Joint Strike Fighter (JSF)

Program History

1993-2000

Background / Program Initiation: 1993

Concept Exploration: 1994

Concept Definition & Design Research: 1995-1996

Concept Demonstration (Ongoing): 1996-2000

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3BSD	Three Bearing Swivel Duct
AAA	Anti-Aircraft Artillery
A/A	Air-to-Air
AADC	Allison Advanced Development Company
AAM	Air-to-Air Missile
ACA	Associate Contractor Agreement
ACAS	Advanced Close Air Support
ACAT I C	Acquisition Category I, Component
ACAT I D	Acquisition Category I, DoD
ACC	Air Combat Command
ACC/DR	Director of Requirements, Air Combat Command
ACETEF	Air Combat Environment Test & Evaluation Facility, Naval Air Station Patuxent River
ACS	Attitude Control System7
ACTD	Advanced Concept Technology Demonstration
ACWP	Actual Cost of Work Performed
ADCS(A)	Assistant Deputy Chief of Staff (Aviation), U.S. Marine Corps
ADM	Acquisition Decision Memorandum
AEDC	Arnold Engineering Development Center, Tullahoma, TN
AEP	Alternate Engine Program
AESA	Active Electronically Scanned Array
AFAST	Affordable Fighter Aft-Fuselage Structures Technology
AFEWES	Air Force Electronic Warfare Evaluation Simulation
AFFTC	Air Force Flight Test Center
AFL	Boeing Avionics Flying Laboratory
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFTI	Advanced Fighter Technology Integration
A/F-X	Advanced Attack Fighter
AF/XO	Plans & Operations office under the Chief of Staff of the Air Force
AF/XOR	Requirements office within AF/XO
A/G	Air-to-Ground
AIA	Autonomous Intelligent Agent
AIM	Air Intercept Missile
AIS	Active Inceptor System *or* Automated Information System
AIT	Advanced Integration Test
ALAFS	Advanced Lightweight Aircraft Fuselage Structure
AMAD	Airframe Mounted Accessory Drive
AMRAAM	Advanced Medium Range Air-to-Air Missile
AL	Autonomic Logistics
ALP	DARPA Advanced Logistics Program
AMT	Accelerated Mission Test
AOA	Analysis of Alternatives
APB	Acquisition Program Baseline
ARPA	Advanced Research Projects Agency
ASAP	Aircrew Systems Advisory Panel
ASAG	Acquisition Strategy Advisory Group

ASC	Aeronautical Systems Center
ASD/C3I	Assistant Secretary of Defense for C3I
ASN(RD&A)	Assistant Secretary of the Navy for Research, Development & Acquisition
ASTO	Advanced Systems Technology Office
ASTOVL	Advanced Short Takeoff/Vertical Landing
ATA	Advanced Tactical Aircraft
ATF	Advanced Tactical Fighter
ATPRG	Arms Transfer Policy Review Group
AVPHM	Air Vehicle Prognostics and Health Management
AVSEP	Avionics Virtual Systems Engineering Prototyping
AVT	Advanced Vectored Thrust
AWACS	Airborne Warning and Control System
A-X	Advanced Attack
BAA	Broad Agency Announcement
BAe	British Aerospace
BAFO	Best and Final Offer
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
BRAWLER	Engagement level air-to-air model
BUR	Bottom-Up Review
BVR	Beyond Visual Range
C4I	Command, Control, Communications, Computers, & Intelligence
C4ISP	Command, Control, Communications, Computers, & Intelligence Support Plan
C4ISR	Command, Control, Communications, Computers, & Intelligence, Surveillance, & Reconnaissance
C&A	Certification and Accreditation
CAAG	Certification and Accreditation Advisory Group
CAI	Composite Affordability Initiative
CAIG	Cost Analysis Improvement Group
CAIV	Cost as an Independent Variable
CALF	Common Affordable Lightweight Fighter
CAS	Close Air Support
CBD	*Commerce Business Daily*
CCB	Configuration Control Board
CC&D	Camouflage, Concealment, & Deception
CDA	Concept Demonstrator Aircraft
CDDR	Concept Definition & Design Research
CDE	Common Demonstrator Engine
CDP	Concept Demonstration Phase
CDR	Critical Design Review
CDRL	Contract Deliverable Report Lists
CE	Concept Exploration *or* Cost Estimate
CER	Cost Estimating Relationships
CE/D	Concept Exploration and Definition
CFD	Computational Fluid Dynamics
CFE	Contractor-Furnished Equipment
CFI	Call for Improvements
CG	Center of Gravity
CIA	Central Intelligence Agency

CIMFAC	Combat Information Management for Fighter Aircraft Cockpits
CISA	C4ISR Integration and Supportability Agency
CJCS	Chairman of the Joint Chiefs of Staff
CLRS	Composite Longer Range Scenario
CM&S	Constructive Modeling and Simulation
CMC	Commandant of the Marine Corps
CNA	Center for Naval Analysis
CNI	Communications/Navigation/Identification
CNO	Chief of Naval Operations
CNR	Chief of Naval Research
COEA	Cost & Operational Effectiveness Analysis
CONOPS	Concept of Operations
COPT	Cost & Operational Performance Tradeoffs
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-The-Shelf
CPI	Cost Performance Index *or* Choke Point Interdiction *or* Critical Program Information
CRs/DRs	Clarification Requests/Deficiency Reports
CRB	Configuration Review Board
CSAF	Chief of Staff of the Air Force
CSCSC	Cost-Schedule Control System Criteria
CSTP	Concept Specific Technology Program
CTOL	Conventional Takeoff & Landing
CTP	Common Technology Program
CTTA	Certified TEMPEST Technical Authority
CTWG	Combined Test Working Group
CV	Cost Variance *or* Aircraft Carrier
CY	Calendar Year
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive
DARO	Defense Airborne Reconnaissance Agency
DARPA	Defense Advanced Research Projects Agency
DASN(AIR)	Aviation deputy in the office of the Assistant Secretary of the Navy for Research, Development & Acquisition
DCA	Defensive Counter Air
DCS(A)	Deputy Chief of Staff (Aviation), U.S. Marine Corps
DDR&E	Director of Defense Research & Engineering
Dem/Val	Demonstration & Validation
DERA	Defence Evaluation Research Agency (see also DRA)
DIA	Defense Intelligence Agency
DIADS	Digital Integrated Air Defense System
DISA	Defense Information Systems Agency
DL	Direct Lift
DLA	Defense Logistics Agency
DMSO	Defense Modeling and Simulation Office
DNN	Denmark, The Netherlands and Norway
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOE	Design of Experiment
DoN	Department of the Navy

DPA&E	Director, Program Analysis & Evaluation in OSD
DPD	Deputy Program Director
DPG	Defense Planning Guidance
DPM	Deputy Program Manager
DRA	Defence Research Agency (United Kingdom)
DRPM	Direct Reporting Program Manager
DSB	Defense Science Board
DSMC	Defense Systems Management College
DT	Developmental Test
DTSE&E	Director, Test, Systems Engineering and Evaluation
DUSD(AR)	Deputy Under Secretary of Defense, Acquisition Reform
EADSIM	Enhanced Air Defense Simulation
EA	Environmental Assessment
EA/EP	Electronic Attack/Electronic Protection
EC	Executive Committee
ECCM	Electronic Counter-Counter Measures
ECM	Electronic Counter Measures
EHA	Electro-Hydrostatic Actuator
EMD	Engineering & Manufacturing Development
EMDP	Engine Model Derivative Program
EO-DAS	Electro-Optical Distributed Aperture System
EO-TS	Electro-Optical Targeting System
EO/IR	Electro-Optical/Infrared
EPS	Electrical Power System
ESA	Electronically Scanned Array
ESAMS	Enhanced Surface-to-Air Missile Simulation
ESC	Executive Steering Committee *or* Escort *or* Electronic Systems Center
ESH	Environmental, Safety and Health
ESM	Electronic Support Measures
ESS	Electronic Source Selection
EW	Electronic Warfare
EW/CM	Electronic Warfare and Counter Measures
EXCOM	Executive Committee
FAC	Forward Air Controller
FDR	Final Design Review
FETT	First Engine To Test
FFRDC	Federally Funded Research and Development Center
FLCS	Flight Control Activators
FLIR	Forward-Looking Infrared
FLOT	Forward Line of Troops
FMS	Foreign Military Sales *or* Full Mission Simulation
FPQ	Full Production Qualification
FOA	Future Offensive Aircraft
FPPD	Financial Policies and Procedures Document
FPT	Force Process Team
FSB	Fan Stream Burning
FTA	Fatigue Test Article
FTC	Federal Trade Commission
FY	Fiscal Year

FYDP	Future (formerly Five) Years Defense Program
g	Gravitational Force
GCLF	Gas-Coupled Lift Fan (same as GDLF)
GCS	Generic Composite Scenario
GCSS	Global Combat Support System
GDLF	Gas-Driven Lift Fan (same as GCLF)
GE	General Electric
GESP	Pratt & Whitney Government Engines and Space Propulsion
GFE	Government-Furnished Equipment
GPS	Global Positioning System
HARM	High-speed Anti-Radiation Missile
HAZMAT	Hazardous materials
HCAT	Hard Chrome Alternatives Team
HCF	High Cycle Fatigue
HDMP	High Density Microwave Packaging
HF	High Frequency
HGI	Hot Gas Ingestion
HLA	High Level Architecture
HMD	Helmet-Mounted Display
HRSAR	High-Resolution Synthetic-Aperture Radar
HVOF	High Velocity Oxygen Fuel
IADS	Integrated Air Defense System
IBR	Integrally Bladed Rotor
ICBM	Intercontinental Ballistic Missile
ICP	Integrated Core Processing
ICT	Integrated Combat Turnaround
IDEFF	Inlet Duct, Edges, and Front Frame
IDR	Initial Design Review
I/F	Interface
IFR	Initial Flight Release
IHAVS	Integrated Helmet Audio Visual System
IHPTET	Integrated High Performance Turbine Engine Technology
IIPT	Integrating Integrated Product Team
IMC	Instrument Meteorological Conditions
IMS	Integrated Master Schedule
INS	Inertial Navigation System
INT	Interdiction Mission
IOC	Initial Operational Capability
IPO	International Programs Office
IPPD	Integrated Product and Process Development
IPR	Interim Program Review *or* In-Progress Review
IPT	Integrated Product Team
IR	Infrared
IRAD *or* IR&D	Independent Research & Development
IRST	Infrared Search and Track
ISP	Intelligence Support Plan
ISS	Integrated Sensor System
ITEMP	Interim Test and Evaluation Master Plan

JAAD	JSF Avionics Architecture Definition
JAF	Joint Attack Fighter
JAST	Joint Advanced Strike Technology
JCCM	Joint Common Cost Model
JCIDO	Joint Combat Identification Office
JCS	Joint Chiefs of Staff
JDAM	Joint Direct Attack Munition
JDIS	Joint Distributed Information System
JEFX	Joint Expeditionary Force Experiment
JFACC	Joint Forces Air Component Commander
JFC	Joint Forces Commander
JIFL	JSF Imagery For Lethality
JIMM	Joint Interim Mission Model
JIRD	Joint Initial *or* Interim Requirements Document
J/IST	JSF (formerly JAST)/Integrated Subsystems Technology
JLME	Joint Logistics Modeling Environment
JMAA	Joint Mission Area Analysis
JMCATS	JSF Manufacturing Capability Assessment and Toolset
JMD	JSF Manufacturing Demonstration
JORD	Joint Operational Requirements Document
JPAP	Joint Paintless Aircraft Program
JPL	NASA Jet Propulsion Laboratory
JPO	JAST *or* JSF *or* Joint Program Office
JROC	Joint Requirements Oversight Council
JMS	Joint (Strike Fighter) Model Specification
JSAFCTS	Joint Services Advanced Flight Controls Technology Studies
JSB	Join Synthetic Battlespace
JSF	Joint Strike Fighter
JSFPO	Joint Strike Fighter Program Office
JSOW	Joint Stand-Off Weapon
JSSA	Joint Stealth Strike Aircraft
JSSG	Joint Service Specification Guides
JSTAR	Joint System Threat Assessment Report
JSTWG	JSF System Threat Working Group
JSTARS	Joint Surveillance Target Attack Radar Systems
JSTRAP	Joint System Training Plan
JTA	Joint Technical Architecture
JTAAMO	Joint Tactical Air-to-Air Missile Office
JTF	Joint Test Force
JWG	Joint Working Group
KCAS	Knots Calibrated Airspeed
KPP	Key Performance Parameters
L+L/C	Lift plus Lift/Cruise
LAC	Logistics Advisory Council
LADC	Lockheed Advanced Development Company (Skunk Works)
LAN	Local Area Network
LaRC	NASA Langley Research Center
LCC	Life-Cycle Cost

LEFD	Leading Edge Flap Drive
LMTAS	Lockheed Martin Tactical Aircraft Systems
LID	Lift Improvement Devices
LO	Low Observable/Observability
LOA	Letter of Offer and Acceptance
LPQ	Limited Production Qualification
LPT	Low Pressure Turbine
LRIP	Low-Rate Initial Production
LSPM	Large Scale Powered Model
LWF	Lightweight Fighter
M&S	Modeling & Simulation
MADP	Manufacturing Affordability Development Program
MAJCOM	Major Command (Air Force)
MANPAD	Man-Portable Air Defense System
ManTech	Manufacturing Technology
MDA	Milestone Decision Authority *or* McDonnell Douglas Aircraft Corporation
MDST	Missile Defense Space Tool
MEA	More Electric Aircraft
MFA	Multi-Function Aperture
MFD	Multi-Function Display
MFS	Manned Flight Simulator
MFVT	Mixed Flow Vectored Thrust
MIL-AASPEM	Man-In-the-Loop Air-to-Air System Performance and Evaluation Model
MIRFS	Multi-function Integrated Radio Frequency Systems
MIS	Management Information Systems
MNFP	Multi-National Fighter Production
MNS	Mission Needs Statement
MOA	Memorandum of Agreement
MoBIDEC	Model Based Intelligent Digital Engine Control
MoD	Ministry of Defense (United Kingdom)
MOE	Measure of Effectiveness
MOT&E	Multinational Operational Test & Evaluation
MOU	Memorandum of Understanding
MPP	Modernization Planning Process
MRC	Major Regional Contingency *or* Major Regional Conflict
MRF	Multi-Role Fighter
MS&A	Modeling, Simulation & Analysis
MSAP	Maintenance Systems Advisory Panel
MSSP	Modeling and Simulation Support Plan
MTI	Moving Target Indication
MWS	Missile Warning System
MxITL	Maintainer-in-the-Loop
N-8	Resources, Policies and Requirements office under the Chief of Naval Operations
N-88	Naval Aviation Requirements office (subset of N-8)
N-89	Navy Special Programs office (subset of N-8)
N-91	Naval Test & Evaluation office
NAIC	National Air Intelligence Center
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration

NASP	National Aero-Space Plane
NATF	Naval Advanced Tactical Fighter
NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAWC	Naval Air Weapons Center
NAWC/AD	Naval Air Warfare Center, Aircraft Division
NAWC/WD	Naval Air Warfare Center, Weapons Division
NGC	Northrop Grumman Corporation
NGIC	National Ground Intelligence Center
NGMM	Next Generation Mission Model
NIAP	National Information Assurance Program
NIMA	National Imagery and Mapping Agency
NIPO	Navy International Program Office
NIST	National Institute of Standards and Technology
NLR	National Aerospace Laboratory, The Netherlands (*Nationaal Lucht- en Ruirntevaartlaboratoriurn*)
NRAC	Naval Research Advisory Council
NRO	National Reconnaissance Office
NSA	National Security Agency
O&S	Operations & Support *or* Operating & Sustainment
OAG	Operational Advisory Group
OARF	NASA Ames Outdoor Aerodynamic Research Facility
ODC	Offices of Defense Cooperation
ODS	Operation Desert Storm
ODDR&E	Office of the Director of Defense Research & Engineering
OEM	Original Equipment Manufacturers
OESCD	Operational Employment and Support Concept Document
OIPT	Overarching Integrated Product Team
OMB	Office of Management and Budget
OMG	Object Management Group
ONI	Office of Naval Intelligence
ONR	Office of Naval Research
ORD	Operational Requirements Document
OSAT	Open System Ada Technology
OSD	Office of the Secretary of Defense
OT	Operational Test
OUSD(A&T)	Office of the Under Secretary of Defense (Acquisition & Technology)
OUSD(AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
P2IPT	Program Protection IPT
PA&E	Program Analysis & Evaluation in the Office of the Secretary of Defense
PBS	Performance-Based Specification
PD	Program Director
PDR	Preliminary Design Review
PDRR	Program Definition and Risk Reduction
PEO	Program Executive Officer
PESHE	Programmatic Environmental, Safety and Health Evaluation
PFQ	Preliminary Flight Qualification
PHM	Prognostics and Health Management

PI	Program Integration
Pk	Probability of Kill
PM	Program Manager
PMAD	Power Management and Distribution
PMAG	Program Management Advisory Group
PMF	Philips Machinefabrieken
PMR	Program Management Review
POM	Program Objective Memoranda
PPDP	Program Protection Development Plan
PPP *or* P^3	Program Protection Plan
PR	Program Review
PRDA	Program Research and Development Agreements
PRR	Production Readiness Review
PTMS	Power Thermal Management System
PVI	Pilot/Vehicle Interface
PVS	Program Visibility System
PW *or* P&W	Pratt & Whitney
PWSC	Preferred Weapon System Concept
QDR	Quadrennial Defense Review
QFD	Quality Function Deployment
R&D	Research & Development
R&M	Reliability and Maintainability
RADGUNS	Radar Directed Gun System Simulation
RAE	Royal Aeronautical Establishment (United Kingdom)
RAF	Royal Air Force (United Kingdom)
RALS	Remote Augmented Lift Systems
RCS	Radar Cross Section
RDT&E	Research, Development, Test and Evaluation
RF	Radio Frequency
RFI	Request for Information
RFP	Request for Proposals
RN	Royal Navy (United Kingdom)
RQ	Requirements
RR	Rolls-Royce
S&T	Science & Technology
SA	Situational Awareness
SAE	Service Acquisition Executive
SAF/AQ	Assistant Secretary of the Air Force (Acquisition)
SAF/AQL	Electronic & special projects directorate within SAF/AQ
SAF/AQP	Strategic & tactical aircraft directorate within SAF/AQ
SAF/IA	Assistant Secretary of the Air Force (International Affairs)
SAM	Surface-to-Air Missile
SAMP	Single Acquisition Management Plan
SAP	Special Access Program
SAR	Synthetic Aperture Radar
SASSY	Shared Aperture Sensor System
SAVE	Simulation Assessment Validation Environment
SBA	Simulation Based Acquisition

SC	JSF Program Protection and Security Directorate
SCI	Scaled Composites Inc.
SCI/RT	Scalable Coherent Interface / Real Time
SDE	Synergistic Demonstrator Engine
SDLF	Shaft-Driven Lift Fan
SE	Systems Engineering *or* Self Escort
SEAD	Suppression of Enemy Air Defense
sel	selected (for promotion)
SERB	Systems Engineering Review Board
SERDP	Strategic Environmental Research and Development Program (DoD/DOE/EPA)
SES	Senior Executive Service
SigMA	Lockheed Martin Signature Measurement Aircraft
SimAF	WPAFB Simulation Facility
SIRMA	Structurally Integrated Reconfigurable Multifunction Apertures
SITM	Software Infrastructure Technology Maturation
SLO	Supportable Low Observable
SME	Society of Manufacturing Engineers
SOO	Statement of Objectives
SoS	System of Systems
SOW	Statement of Work
SPAWAR	Space and Naval Warfare Systems Command
SSA	Source Selection Authority
SSAA	System Security Authorization Agreement
SSAC	Source Selection Advisory Council
SSC	System Security Concept
SSE	System Security Engineering
SSEB	Source Selection Evaluation Board
SSF	STOVL Strike Fighter
SSOI	Summary Statement of Intent
SSPM	Small Scale Powered Model
STA	Static Test Article
STAR	System Threat Assessment Report
STI	Strategic Target Interdiction
STOVL	Short Takeoff/Vertical Landing
STT	Strategy-to-Task-to-Technology
SUIT	Subsystems Integration Technology
SV	Schedule Variance
SWCE	Strike Warfare Collaborative Environment
SWEG	Synthetic Warfare Environment Generator
TAA	Technical Assistance Agreement
TAC	Total Accumulated Cycles
TACAIR	Tactical Aircraft
TAD	Technology Availability Date
TADL	Threat Air Defense Lab
TBD	To Be Determined
TCA	Technical Collaborative Agreement
TCS	Television Camera Set
TCSEC	Trusted Computer Security Evaluation Criteria
T&E	Test and Evaluation
Tech Mat	Technology Maturation

T/EMM	Thermal/Energy Management Module
TEMP	Test & Evaluation Master Plan
TEMPEST	Telecommunications and Electrical Machinery Protected From Emanations Security
TFX	Tactical Fighter, Experimental
TI	Technical Importance
TLAM	Tomahawk Land Attack Missile
TM	Technology Maturation Directorate
TOR	Tentative Operational Requirement
TPIPT	Technical Planning Integrated Product Teams
TSPR	Total System Performance
TTG	Time-To-Go
UAV	Unmanned Air Vehicle
UCAV	Unmanned Combat Air Vehicles
UI	Unit Interdiction
UK	United Kingdom
URF	Unit Recurring Flyaway (Cost)
USAF	U.S. Air Force
USD(A)	Under Secretary of Defense for Acquisition (now USD(AT&L))
USD(A&T)	Under Secretary of Defense for Acquisition & Technology (now USD(AT&L))
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology & Logistics
USMC	U.S. Marine Corps
USN	U.S. Navy
VAAC	Vectored-thrust Aircraft Advanced Control
VCJCS	Vice Chairman of the Joint Chiefs of Staff
VITPS	Vehicle Integration Technology Planning Studies
VM	Virtual Manufacturing
VMS	Vehicle Management System
VOC	Volatile Organic Compound
V/STOL	Vertical and/or Short Takeoff and Landing
VSWE	Virtual Strike Warfare Environment
VTC	Video Teleconference
VTOL	Vertical Takeoff and Landing
VV&A	Verification, Validation & Accreditation
WBS	Work Breakdown Structure
WCMD	Wind Corrected Munitions Dispensers
WIPT	Working-level Integrated Product Team
WL	Air Force Wright Laboratories
WMD	Weapons of Mass Destruction
WOD	Wind Over Deck
WPAFB	Wright-Patterson Air Force Base
WSC	Weapon System Contractor

1 Introduction

The Joint Strike Fighter (JSF) Program is the focal point within the U.S. Department of Defense (DoD) for defining and developing an affordable family of next-generation strike fighters for the U.S. Navy, Air Force, and Marine Corps, the UK Royal Navy, and the armed services of other U.S. allies. The vision of the JSF Program is to:

- Be the model acquisition program for Joint service and international cooperation
- Develop and produce an **affordable** next-generation strike fighter and **sustain it worldwide**[1]

Specifically, the Joint Strike Fighter will meet the following service needs:

- **United States Navy:** A first-day-of-the-war, survivable, carrier-based (CV) strike fighter to complement the F/A-18E/F (480 JSF aircraft)
- **United States Air Force:** A multirole, conventional take-off and landing (CTOL) aircraft to replace the F-16 and A-10, and complement the F-22 (1,763 JSF aircraft)
- **United States Marine Corps:** A supersonic, short take off/vertical landing (STOVL) aircraft to replace the AV-8B and the F/A-18C/D (609 JSF aircraft)
- **United Kingdom Royal Navy:** A supersonic STOVL aircraft to replace the Sea Harrier F/A.2 aboard UK aircraft carriers (60 JSF aircraft)
- **United Kingdom Royal Air Force:** Supersonic STOVL aircraft to replace the Harrier GR.7 (90 JSF aircraft) [2,3]

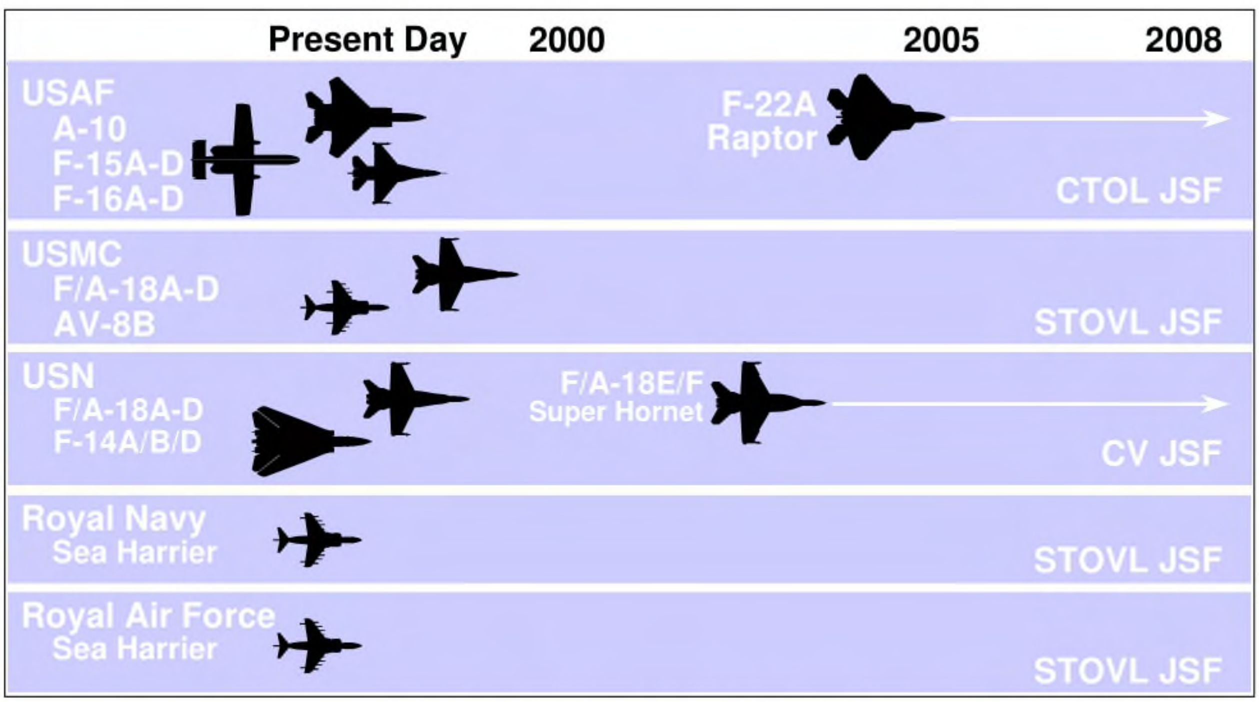

Figure 1: The Future of Tactical Aviation[4]

The UK is a Full Collaborative Partner in the JSF Program. Denmark, the Netherlands, Norway, Canada, Italy, Singapore, Turkey and Israel have also joined the program. Additional foreign governments may eventually join the program and/or procure the JSF to meet their future tactical aircraft requirements.

The JSF Program—originally the Joint Advanced Strike Technology (JAST) Program—was initiated in late 1993 as a result of the Department of Defense's (DoD) Bottom-Up Review (BUR) of U.S. military forces and modernization plans. The major BUR results, with respect to tactical aviation, were to continue the ongoing Air Force F-22 and Navy F/A-18E/F programs, cancel the Air Force Multi-Role Fighter (MRF) and the Navy-led Advanced Attack/Fighter (A/F-X), curtail F-16 and F/A-18C/D procurement, and begin the JAST program. Not initially a weapon system acquisition program, the JAST Program was to lay the groundwork for one or more future acquisition programs. The JAST charter called for developing affordable Joint requirements, identifying advanced technologies with Joint application and the potential to reduce life cycle cost, and maturing such technologies to a low risk status by the year 2000. This year was selected to enable entry of one or more strike weapons systems into Engineering and Manufacturing Development (EMD) in 2001.[5]

1.1 Program Philosophy

The JAST/JSF Program was also chartered to *do business differently* and to demonstrate leadership in acquisition reform, particularly in the area of paperless acquisition processes. Accordingly, the recommendations of the 1985-86 Packard Commission and other recent acquisition reform panels were enthusiastically embraced by both warfighters and technologists; they work together in a truly joint-service program, with *no single executive service* in charge of the program. Directorship rotates between the Departments of the Air Force and the Navy, and whichever Department the Program Director belongs to, she/he reports to the other Department's service Acquisition Executive. The Departments share representation in every organization within the JSF Program Office (JSFPO).

From the beginning, the JAST/JSF Program has focused on affordability from a life-cycle perspective: not just reducing the initial acquisition cost, but *also operating & sustainment* costs. The single most influential discriminator in technology investment decisions has been the potential for each candidate technology to lower the projected life cycle cost of the JSF. To reach affordability goals, the JPO works in partnership with industry to identify innovative ways to reduce costs.

The JAST/JSF Program completed a Concept Exploration (CE) Phase in December 1994, a Concept Definition & Design Research (CDDR) Phase in November 1996, and is currently in the Concept Demonstration Phase (CDP) until 2001 when EMD commences. Through all of these phases, the primary thrusts have been: requirements definition, technology maturation, and evolving weapon system concepts.

1.2 Requirements Definition

The JAST/JSF approach to operational requirements is to facilitate mission level requirements development with both operators and maintainers from within the Program Office. In this setting, personnel from the participating services work with government and industry technologists to develop affordable, technically feasible, joint-service requirements. Requirements development began with a Strategy-to-Task-to-Technology (STT) analysis which defined a series of linkages from national strategy, to campaign objectives, operational objectives, operational tasks, weapon system attributes, and finally, individual technologies. At each level, specific relationships (e.g., between weapon system attributes and operational tasks) were established through a method called Quality Function Deployment (QFD). The resulting hierarchical structure provided for traceability and consistency in the entire requirements process.

Joint-service, campaign-level simulations ("wargames") were conducted to validate needs and establish critical attributes for a strike fighter force operating in the year 2010. The results of the initial series of wargames were presented in a Joint Mission Area Analysis (JMAA) report in mid-1995. The first Joint Initial Requirements Document (JIRD I) was released and endorsed by the Joint Requirements Oversight Council (JROC) in August 1995. JIRD II was released in June 1997 and JIRD III in October 1998. A series of Cost and Operational Performance Trades (COPTs) were initiated in concert with the JIRD process to

assure a continuing balance between capability and affordability. The COPT process ensures that JSF requirements, as articulated in the JIRD and eventually in a Joint Operational Requirements Document (JORD), are indeed affordable. The draft JORD was completed in April 1999, and the final JORD was signed by the JROC on 13 March 2000.

1.3 Technology Maturation

JPO Tech Mat efforts coincide with two key recommendations of the Packard Commission: i.e., 1) apply advanced technology to reduce cost, not just to increase performance; and 2) demonstrate advanced technologies prior to EMD start. From an initial database of over 500 candidate-technology projects, the JAST Technology Maturation Integrated Product Teams (IPTs) selected 75 of the most promising projects, based on joint-service applicability and the potential to reduce *life-cycle cost.* Decisions were based on analysis by each IPT, in conjunction with the QFD process, and confirmed with the industry. In short, technology projects were only funded if they could "buy their way onto the airplane" from an *affordability* perspective while providing real benefits to the weapon system concepts of the prime contractors.

Several existing Science & Technology (S&T) efforts in the Air Force, Navy, Defense Advanced Research Projects Agency (DARPA), and National Aeronautics & Space Administration (NASA) were leveraged to reduce risk. Several demonstration programs were initiated to accomplish pre-EMD risk reduction beyond ordinary S&T efforts. For example, the JSF Integrated Subsystems Technology (J/IST) program will demonstrate integration concepts and technologies to dramatically reduce weight and parts count while improving the efficiency and supportability of JSF subsystems. The Multi-function Integrated Radio-Frequency Systems (MIRFS) program is maturing technology for an affordable, multi-function RF aperture—historically one of the most expensive parts of an avionics suite. Other complementary avionics projects support an affordable, adaptable open systems avionics architecture. The JSF Paintless Aircraft Program (JPAP) has conducted flight tests of appliqué coatings, which offer a lighter, more supportable, and more environmentally friendly alternative to aircraft paint. All of the Tech Mat projects have been structured to reduce technical risk to acceptable levels prior to EMD start.

1.4 Weapon System Concept Exploration and Development

The JAST Program initially explored a wide range of potential strike warfare concepts using six-month, Concept Exploration (CE) study contracts awarded to industry in May 1994. A key finding of these studies was that a "tri-service family" of aircraft was technically feasible and represented the most affordable solution to collective joint-service needs. Substantial savings seemed to be achievable. The tri-service family would entail a single basic airframe design with three distinct variants: CTOL for the U.S. Air Force; STOVL for the U.S. Marine Corps (and, subsequently, the UK Royal Navy); and a CV variant for the U.S. Navy. It appeared that maximum affordability would be achieved by determining the optimum level of commonality "from the ground up," rather than by specifying an arbitrary percentage of commonality—a philosophy that was partly to blame for the failure of some past multi-service programs. In this way, high-cost items such as the avionics would naturally be highly common, while certain essential service-unique requirements such as carrier suitability and STOVL capability could still be accommodated.

Two critical decisions were made during the CE Phase: the JAST family of aircraft would be single-crew and single-engine. All of the Weapon System Contractors identified these as major cost drivers. Independent studies by the Johns Hopkins University Applied Physics Laboratory and the Georgia Tech Research Institute supported the choice of a single engine, assuming that improved engine reliability would make the next-generation single-engine strike fighter as reliable as current-generation twin-engine fighters. The choice of a single-crew aircraft was accepted – subject to continued studies and appropriate Tech Mat—on the projection that a single crewmember could perform all intended missions.

Boeing, Lockheed Martin, McDonnell Douglas (teamed with British Aerospace), and Northrop Grumman were awarded fifteen-month Concept Definition and Design Research (CDDR) contracts in December 1994; shortly after contract award, Northrop Grumman joined the McDonnell Douglas/British Aerospace team. These companies developed:

- Specific weapon system designs based on a tri-service family of aircraft
- Risk reduction plans for the transition of critical technologies into the EMD phase with low technical risk, and moderate integration risk

The contractors refined their Preferred Weapon System Concepts (PWSCs) and performed a number of risk reduction activities (e.g., wind tunnel tests, powered-model STOVL tests, radar cross section (RCS) model tests, and engineering analysis). Early in this phase, all three contractor teams selected derivatives of the Pratt & Whitney (P&W) F119 engine to power their aircraft. Accordingly, in November 1995, P&W was awarded a contract for preliminary design of each of the primary JSF engine concepts.

Concurrently, General Electric was awarded a contract to investigate whether the GE F110 or YF120 could be developed into an alternate engine for one or more of the JSF variants. This effort will preserve future competitive options for engine procurement during the JSF production phase. In early 1996, the YF120 was identified as the "best fit" for a tri-service solution and GE initiated preliminary design efforts.

Several Defense Acquisition Board (DAB)-level program reviews were conducted in late 1995. These resulted in approval to release the Concept Demonstration Phase (CDP) Request for Proposals (these reviews essentially served the purpose of a Milestone I, although JAST was not a formal acquisition program at that time). The first draft CDP RFP was released in December 1995, and the final RFP in March 1996. By that time the JAST program name had changed to JSF. In May 1996, JSF was designated an Acquisition Category I, DoD (ACAT I D) acquisition program. In June, the weapon system prime contractors submitted their CDP proposals. A formal Milestone I Acquisition Decision Memorandum was signed by the Under Secretary of Defense (Acquisition & Technology) on 15 November 1996, clearing the way for the award of CDP prime contracts to Boeing and Lockheed Martin on 16 November 1996. The current configurations of the two companies' JSF designs are shown in Figure 2.

Figure 2: Lockheed Martin (left) and Boeing (right) JSF Weapon System Concepts

1.5 Current Phase

The JSF Program's current CDP is analogous to a tailored Program Definition and Risk Reduction (PDRR) in current DoD acquisition terminology (DoDD 5000.2R). In this phase:

- Two Concept Demonstrator Aircraft (CDA) have been built and are being flight-tested by each of the two Weapon System Contractor (WSC) teams to demonstrate key capabilities of their respective

concepts including: commonality/modularity; STOVL hover and transition; and low-speed carrier approach handling qualities.

- Each WSC team is developing and refining their respective Preferred Weapon System Concept (PWSC) designs, stressing affordability, supportability, and the integration of technologies to achieve full mission capabilities.
- Propulsion system development will provide CDA flight test engines and STOVL lift systems, a primary propulsion system design for each PWSC, and an alternate engine core design for future development during subsequent phases of the JSF Program.
- Technology risks in key areas will continue to be reduced through generic and concept-specific demonstrations that will include simulation, ground testing, and flight testing.
- Requirements analysis and cost/performance trades, leading to the release of the JORD in 2000.
- All necessary planning and documentation, required for the Milestone II decision (EMD start), will be accomplished.

Upon completion of CDP activities, a single WSC team will be selected to enter EMD in 2001. Initial Operational Capability (IOC) of all variants of JSF is projected to occur in the 2010-2012 timeframe: USMC in 2010, USAF in 2011, and USN and UK in 2012. The overall JSF schedule from initiation through EMD is shown in Figure 3.

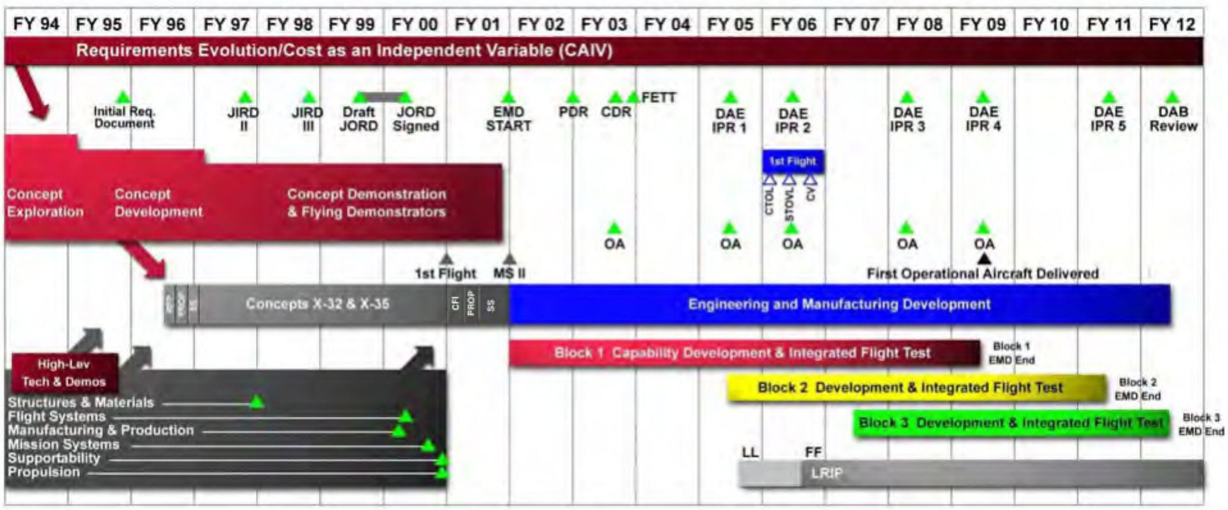

Figure 3. Overall JSF Program Schedule.

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1 Kenne, Leslie, Brig Gen USAF, *Joint Strike Fighter Program Vision*, briefing to the Joint Strike Fighter Program Office, 14 August 1997.

2 Steidle, Craig E., RADM USN, "The Joint Strike Fighter Program," *Johns Hopkins APL Technical Digest*, Vol. 18 No. 1, January-March 1997.

3 Boeing, "JSF Program Overview, Public Release", 23 November 1999.

4 *Ibid.*

5 *Charter for the Joint Advanced Strike Technology (JAST) Program*, approved by John M. Deutch, Deputy Secretary of Defense, 12 August 1994.

2 Joint Advanced Strike Technology (JAST) Program Initiation

2.1 Background: Prior Programs

Several tactical aircraft acquisition programs during the 1980s and early 1990s influenced the decision to initiate the JAST Program. To explain their importance, these programs are described briefly below.

2.1.1 Advanced Tactical Aircraft (ATA) / A-12

The U.S. Navy Advanced Tactical Aircraft (ATA) program began in the early 1980s as a low observable replacement for the Grumman A-6 Intruder in the carrier-based, medium-attack role. In 1986, the U.S. Air Force became involved, and considered the ATA as a potential replacement for the F-111. By the late 1980s, a team consisting of McDonnell Douglas and General Dynamics had been selected to develop the ATA, now designated the A-12, as a long-range, subsonic aircraft with a large internal weapons load including air-to-surface and air-to-air weapons. Following the disclosure of severe cost and schedule overruns and technical problems in late 1990, the A-12 program was canceled on 7 January 1991.[1]

Figure 4: A-12 Mockup

2.1.2 Advanced Tactical Fighter (ATF / F-22) and Naval ATF (NATF)

The U.S. Air Force initiated the Advanced Tactical Fighter (ATF) Program in the early 1980s, approximately the same time that the ATA/A-12 program was started. The ATF Program was established in order to develop an advanced front-line air superiority fighter to ultimately replace the F-15. Concept Definition was accomplished from 1981-1986, and Demonstration/Validation (Dem/Val) from 1986-1990. Two competing contractor teams, Lockheed/Boeing/General Dynamics, and Northrop/McDonnell Douglas, participated in Dem/Val. The ATF Dem/Val phase included extensive ground-based technology demonstrations as well as avionics flying laboratory demonstrations, flight testing of prototype air vehicles (the Lockheed/Boeing/General Dynamics YF-22 and the Northrop/McDonnell Douglas YF-23). In addition, two competing engines were developed for Dem/Val, the P&W YF119 and the GE YF120. In 1991, the Lockheed/Boeing/General Dynamics F-22 aircraft and the P&W F119 engine were selected to begin EMD.

Essential features of the F-22 are low observables; the capability to sustain supersonic flight speed without afterburning (“supercruise”); advanced, integrated avionics; enhanced maneuverability; and a strong emphasis on supportability. Performance, signature and avionics characteristics are balanced to achieve a “first-look, first-kill” capability. The first flight in the F-22 EMD program was accomplished in September 1997. Initial Operational Capability (IOC) is expected in December 2005. Production of the

F-22 Raptor began in December 1998 when the U.S. Air Force exercised a contract option with Lockheed Martin Corporation for advance procurement of six Low Rate Initial Production aircraft.

Figure 5: F-22 Raptors

Because of the high degree of advanced technology required by both the ATF and the ATA, particularly in the areas of low observables and avionics, the Air Force and Navy pursued shared opportunities for common technology development. Additionally, in the mid-1980s, Congress directed the services to evaluate the possibility of combining the ATF and ATA into a single aircraft.* This was determined to be infeasible due to significant differences in mission requirements. However, the services did agree that the Air Force would consider the ATA as an eventual replacement for the F-111 and F-15E. In turn, the Navy would evaluate a derivative of the ATF to replace the F-14. In late 1988, a Naval ATF (NATF) program office was set up at Wright-Patterson Air Force Base and the existing ATF Dem/Val contracts were modified to include studies of potential Naval ATF variants. However, in early 1991 the NATF was canceled, due in part to an extension of the F-14's service life.[2]

Figure 6: Lockheed Martin NATF Concept

* Congress pursued the objective of combining similar service efforts in advanced technologies as well. For example, in 1987, Congress directed the ATF, A/F-X and RAH-66 (then LHX) programs to engage in a tri-service avionics commonality forum that became known as the Joint Integrated Avionics Working Group (JIAWG). One goal of this group was to seek a common set of form, fit, function, and interface standards for avionics building blocks (i.e., line replaceable modules, buses, processors and protocols) that typically drive avionics costs. Many of the lessons learned from this attempt later helped guide the JAST approach to establishing its open system architecture definition.

2.1.3 Advanced Attack (A-X) / Advanced Attack Fighter (A/F-X)

In January 1991, with the cancellation of the A-12, the Secretary of the Navy directed that planning commence for a new A-6 replacement program. This new program became the known as the A-X, an advanced, "high-end," carrier-based multi-mission aircraft with day/night/all-weather capability, low observables, long range, two engines, two crew, and advanced, integrated avionics and countermeasures. The Air Force participated in this new program from its initiation, still seeking a replacement for the F-111 and, in the longer term, the F-15E and F-117A.

Figure 7: Lockheed A/F-X Concept

The A-X program management was unique in that it had a Direct Reporting Program Manager (DRPM), reporting directly to the Navy Service Acquisition Executive, rather than through a Program Executive Officer (a concept that JAST later adopted). Although the Navy was the lead service for A-X, the Air Force provided a deputy program manager and Air Force personnel held several important positions in the A-X Program Office, which was located in Crystal City, Arlington, Virginia.

A joint Tentative Operational Requirement (TOR) for the A-X was signed by the Chief of Naval Operations on 12 June 1991, and a Mission Needs Statement was approved by the Joint Requirements Oversight Council on 19 June. On 28 June, the Defense Acquisition Board approved Milestone Zero, which started the formal Concept Exploration and Definition (CE/D) phase. The TOR was released to industry at an Industry Day on 28 August, and CE/D contracts of $20M each were awarded to five contractor teams on 30 December 1991 (prime contractor listed first):[3]

- Grumman/Lockheed/Boeing
- Lockheed/Boeing/General Dynamics
- McDonnell Douglas/Vought
- Rockwell/Lockheed
- General Dynamics/McDonnell Douglas/Northrop

These teams conducted concept exploration, technology studies, and preliminary aircraft design activities. The Lockheed/Boeing/General Dynamics team evolved a concept based on the F-22, while the General Dynamics/McDonnell Douglas/Northrop concept was based on their earlier A-12. This latter team was dissolved, however, and their contract terminated, when Lockheed acquired the General Dynamics Aircraft Company in December 1992.[4]

The original A-X/A/F-X CE/D work was due to be completed in September 1992. A solicitation for Demonstration/Validation (Dem/Val) proposals was expected in late 1992, leading to a Dem/Val start in 1994 and EMD in 1996. Under the Navy's original plan, the short Dem/Val phase would consist of design refinements and other risk reduction activities, but would not include flying prototypes. However, in late 1992 Congress directed that the A-X Dem/Val phase also include competitive prototyping. This increased the projected duration of the Dem/Val phase from two to five years. Concurrently, as a result of the termination of the NATF in 1991, increased air-to-air requirements were added to the A-X, prompting a change in the name of the Program from Advanced Attack (A-X) to Advanced Attack/Fighter (A/F-X).[5]

The existing A-X CE/D contracts were extended to reflect a revised Dem/Val strategy to accommodate flying prototypes. The expected IOC date of the newly named A/F-X slipped from 2006 to 2008. A Defense Acquisition Board (DAB) Milestone I Review of the A/F-X Program was expected in Spring 1993; however, the Clinton Administration's Bottom-Up Review (BUR) of U.S. force structure and modernization plans put the A/F-X program on hold pending the outcome of the BUR. An A/F-X Milestone I DAB never took place. On 1 September 1993, the BUR canceled the A/F-X as well as the Air Force's Multi-Role Fighter (MRF, described below), and directed the initiation of the JAST Program. (BUR results are more fully described in Section 2.2.) As a result of the BUR, A/F-X efforts during the latter half of 1993 were directed toward closing out the program and transitioning applicable experience and results to the nascent JAST program. A core of A/F-X personnel performed a large portion of the working-level planning and definition of the emerging JAST Program. The A/F-X CE/D contracts were extended a second time, through 17 December 1993, to allow the contractors sufficient time to bring their activities to a logical conclusion. All A/F-X program operations ended on 31 December 1993.[6, 7, 8]

2.1.4 Multi-Role Fighter (MRF)

The U.S. Air Force's MRF was conceived in 1991 as a relatively low-cost F-16 replacement. Similar in size to the F-16, the MRF was expected to be a single-engine aircraft, with a unit flyaway cost in the range of $35 to $50 million. Several development options were considered, including:[9, 10]

- A modest upgrade to an existing fighter (most likely the F-16)
- A significant upgrade to an existing fighter
- A new stealthy aircraft comparable to the F-16 in performance
- A two-phased approach, featuring a modest F-16 upgrade as "MRF I" for the near-term (IOC 1996), and a completely new aircraft as "MRF II" for the long-term (IOC 2010)

The MRF Program was managed from the Air Force Aeronautical Systems Center (ASC) at Wright-Patterson Air Force Base, Ohio. ASC hosted a planning meeting with industry in October 1991, and issued a request for information (RFI) with responses due in January 1992. The major U.S. aircraft manufacturers began to conduct concept and design studies for the MRF at their own expense.

A formal program start was expected around 1994, so that the MRF would be available to replace a large number of F-16s reaching the end of service life in approximately 2005. The MRF might also replace Air Force A-10s and Navy F/A-18C/Ds. Therefore, providing large numbers of aircraft affordably was a higher priority for the MRF Program than any specific capability enhancements.[11]

However, the post-Cold War defense drawdown made the F-16 service life situation considerably less critical. A reduction in the total number of U.S. Air Force fighter wings meant that the existing aircraft would not be replaced one-for-one. Furthermore, F-16 aircraft flying hours were reduced, allowing F-16s to remain in service longer than originally projected.

In August 1992, the MRF program start was effectively put on hold. Due to budget pressures and the Air Force's commitment to the F-22 program, sufficient funding for a new program start did not appear likely until around 2000. Until then, it was expected that MRF activity would proceed at a low level.

Meanwhile, the Air Force intended to continue production of Block 50 F-16s. By early 1993, however, the MRF's projected IOC had slipped to 2015. Shortly thereafter, the BUR canceled the MRF Program, along with the A/F-X and all USAF F-16 procurement beyond FY94.[12, 13]

2.1.5 F/A-18E/F

The F/A-18E/F Super Hornet was initially proposed in 1991, following the cancellation of the General Dynamics / McDonnell Douglas A-12 program for the U.S. Navy. While replacing U.S. Navy F/A-18As and F/A-18C/Ds, the F/A-18E/F is a growth variant of the F/A-18C/D, with the fuselage stretched by 2 ft. 10 in. and the wing scaled up from 400 sq. ft. to 500 sq. ft. for improved range/payload performance. Other airframe features, as well as new F414 engines, are similarly larger. The F/A-18E/F incorporates some features for radar cross section reduction, including the slanted, 'caret'-shaped engine inlets.[14]

Figure 8: F/A-18E/F During Carrier Landing Qualifications

An EMD contract was awarded to McDonnell Douglas in June 1992 to fund the manufacture of seven flight-test aircraft. Also in 1992, a contract was awarded to General Electric for development of the F414 engine. The F/A-18E/F passed a Critical Design Review (CDR) in June 1994 and first flight occurred in November 1995. Manufacture of the seven flight test aircraft began on 15 September 1997 and was completed in September 1998.[15] The first F/A-18E/F production aircraft was delivered to the U.S. Navy on 18 December 1998, slightly ahead of schedule. The F/A-18E/F is currently in low-rate initial production at Boeing (formerly McDonnell Douglas) facilities in St. Louis, Missouri. IOC is expected in 2000.[16]

2.1.6 Advanced Short Takeoff, Vertical Landing (ASTOVL) Program

The Advanced Short Takeoff, Vertical Landing (ASTOVL) Program started as a research and technology effort in 1983 to support the eventual development of a supersonic, STOVL strike fighter. A five-year U.S./UK Memorandum of Understanding (MOU) was signed in January 1986, establishing a joint management structure headed by the DoD and NASA, and the UK Ministry of Defense (MoD) and Royal Aeronautical Establishment (RAE). Extensive technical support was provided by the U.S. Navy (A more in-depth history of the ASTOVL Program is provided in Appendix A).

Four powered lift concepts were selected for initial study, and preliminary assessments were performed in 1985 while the MOU negotiations were still underway. One or two of these concepts were to be selected for focused technology development and ground demonstrations. However, further study in 1986-87 indicated that none of the original four concepts was completely suitable. Revised concepts evolved, including the Shaft Driven Lift Fan (SDLF) and the Gas Driven (or Gas Coupled) Lift Fan (GDLF or GCLF).

In 1988, the U.S. Congress passed the Nunn-Quayle Research & Development Initiative to fund cooperative efforts between the U.S. and NATO allies. This provided a substantial increase in resources, making eventual flight demonstration a realistic possibility, and brought in the Defense Advanced Research Projects Agency (DARPA) as the lead U.S. agency in the ASTOVL Program.* From 1988 to 1991, additional studies were performed in both countries. Concurrently, the need to consider signature reduction for improved survivability was recognized, and the USMC, USN, and the UK Royal Navy drafted preliminary operational requirements for a STOVL Strike Fighter (SSF) incorporating reduced signatures along with varying degrees of supersonic capability.

When the original ASTOVL MOU expired in 1991, the international program officially ended. However, the airframe and engine companies' design efforts and various government activities continued. A revised DARPA/U.S. Navy ASTOVL Program emerged in early 1992 with the aim of demonstrating an affordable STOVL strike fighter for the U.S. Marine Corps with a Conventional Takeoff and Landing (CTOL) variant for possible U.S. Air Force service. With this new emphasis, the program adopted the name Common Affordable Lightweight Fighter (CALF). Based on the earlier study results, this program focused on the two-lift fan concepts (i.e., SDLF and GCLF). An RFP was issued in August 1992 for a three-year risk reduction phase, and contracts were awarded in March 1993 to Lockheed for the SDLF lift fan concept and McDonnell Douglas (teamed with British Aerospace) for the GCLF lift fan concept. Boeing, with a Direct Lift (DL) concept, and Northrop, with a Lift-plus-Lift/Cruise (L+L/C) concept, subsequently joined the ASTOVL program under cost-sharing and no-cost contracts, respectively.

In 1993, formal negotiations with the UK were begun for a new ASTOVL MOU, which was signed in August 1994. The new MOU applied to the recently started risk reduction phase, which would culminate with Large Scale Powered Model (LSPM) ground tests in 1995-96. Following LSPM testing, one contractor would be selected for a flight demonstration phase, leading to an EMD decision by 2000. However, in October 1994, the U.S. Congress merged ASTOVL into the JAST Program.

Figure 9: Boeing, Lockheed, and McDonnell Douglas ASTOVL Concepts

It is significant that the ASTOVL Program was managed, during the period leading up to its integration with JAST, by DARPA rather than by one of the services. DARPA's charter had recently been expanded, as a result of the 1986 Packard Commission's Report on Defense Management, to specifically include "early prototyping of systems or critical subsystems… before a decision to proceed into full-scale development." ASTOVL was judged to come under this new mandate, and as such there was no formal requirement and no specific plan for EMD and production. The ASTOVL Program therefore did not have out-year funding. This effectively kept ASTOVL out of direct competition and comparison with the other tactical aircraft programs during the BUR period described below.

* The name of this agency has periodically changed between DARPA and ARPA (Advanced Research Projects Agency). For simplicity, it is referred to as DARPA throughout the present document.

2.2 Bottom-Up Review

Initiation of the JAST Program resulted from the BUR, which was formally begun on 23 February 1993. The results were announced on 1 September 1993. The purpose of the BUR was to define a strategy for defense planning in the post-Cold War era. It addressed issues of force structure, modernization, affordability, and other factors related to the United States' ability to achieve its military objectives. The BUR was based on the assumption that the U.S. should maintain the ability to fight and win two near-simultaneous Major Regional Conflicts (MRCs).

One of the major issues facing the BUR was the existence of four tactical aircraft development programs: i.e., the F-22, the F/A-18E/F, the A/F-X, and the MRF. Since 1992, these programs collectively had been criticized by Congress as unaffordable and unnecessary. These four programs would require approximately $33 billion, primarily RDT&E funding, within the Future Years Defense Program (FYDP) planning period, plus increasing production funding beyond the FYDP period for a total of over $300 billion. The BUR team studied the modernization needs of U.S. theater air forces in an effort to define an affordable plan to meet those needs.[17, 18]

2.2.1 Tactical Aviation Alternatives

During the BUR, several concepts surfaced as possible replacements for one or more of the four tactical aircraft programs in question. Replacing both the F-22 and the A/F-X with a single aircraft was proposed. This aircraft could be an "F-22+," a carrier-suitable derivative of the F-22 with air-to-surface enhancements; or an "A/F-X+" with enhanced air-to-air capability for the Air Force; or a new Joint Stealth Strike Aircraft (JSSA). However, any one of these three would be an extremely expensive aircraft, entailing lengthy development and high technical risk. Furthermore, the possibility of combining the most demanding, "high-end" missions of both services into a single aircraft had been studied extensively, attempted once (i.e., the TFX), and rejected several times in the past.[19, 20]

A more realistic alternative was a Joint Attack Fighter (JAF) presented to the BUR jointly by the Navy and Air Force. JAF would be in the "low-to-mid" range of cost, size and capability—somewhere between the A/F-X and the MRF with the following notional characteristics:

- Unit Flyaway Cost: $40–$45 million
- Range: 500 mi.
- Takeoff Gross Weight: 35,000–40,000 lb.
- Low observable characteristics
- F-22 technology; core engines and other technology available by 2000
- Initial Operational Capability (IOC) in 2009
- Mixed internal & external payload, depending on mission
- Modular design for multi-role/multi-service capability

There was also a view—although not universally held—that there could be a short takeoff, vertical landing (STOVL) variant of the JAF.[21, 22]

Four out of five options, briefed to Congress in late April 1993, included the JAF as part of the tactical aircraft modernization package:

- MRF, F/A-18E/F, and {"F-22+" or "A/F-X+"}
- F-22 and JAF
- F-22, F/A-18E/F, and JAF
- A/F-X and JAF
- JAF and {"F-22+" or "A/F-X+"}

As preliminary results were developed, a Defense Science Board (DSB) Task Force was chartered to provide an independent assessment of the BUR's efforts related to tactical aircraft. In a memorandum to the Under Secretary of Defense (Acquisition) (USD(A)) on 14 July 1993, the DSB Task Force presented its findings (emphasis added):

> We do not believe the JAF [*] is sufficiently defined at this point to allow meaningful analysis. Further definition of the concept and technology is required before the JAF can be considered as a program to be compared with the other program alternatives. Two alternative concepts for commonality should be considered: (1) common airframe, or (2) common components. *We believe the second concept deserves greater attention, with the objective to achieve maximum cost commonality during the life cycle of the airframes….*
>
> As noted earlier, JAF is not sufficiently defined at this time… *It does not appear likely that the capabilities described by the Navy and the Air Force are likely to be achieved in a single, common airframe.* Navy interests are necessarily focused on the high end, (with the added demands of carrier suitability), while the Air Force interests are focused on a low cost (probably single engine) MRF.
>
> A more likely solution might be two different airframes, with the objective of developing a common engine (or engine core), common avionics architecture, common weapons (to include racks and launchers) and a process that facilitates manufacturing base commonality for two different airframes… The objective of such a joint effort should be a high degree of cost commonality. An aggressive goal would be to achieve greater than 70% cost commonality during the life cycles of the platforms.
>
> "While we strongly support the need for the A/F-X, we are concerned about the program structure. The current program requires $20 billion of research and development expenditures… A better approach to obtaining high-end capability in limited numbers may be the dual airframe, common components approach which was recommended for JAF….
>
> *Recommendation*
>
> *Broaden and refine the JAF approach to commonality to consider two different airframes, with a common engine (or engine core), common avionics architecture, common weapons, and a manufacturing process to facilitate efficient production of two different airframes and a high degree of cost commonality over the life cycle of the platforms.* It will be necessary to undertake additional effort in concept development and demonstration, supported by an underlying technology program, before such a program can be developed. This approach is recommended for the long-term needs associated with A/F-X and MRF….[23]

This DSB Task Force recommendation became, in essence, the foundation of the JAST program. By early August it was reported that A/F-X and MRF were likely to be canceled and replaced by a new technology demonstration program, and that DoD planned to spend approximately $2 billion on this demonstration program over the period FY94-FY99.[24]

On 11 August 1993, the Secretaries of the Navy and the Air Force were asked to develop a plan for a JAST Program (see Appendix B). The program was conceived to focus on common component development (engines, avionics, ground test and training equipment) and the application of technologies to enable commonality and reduce the cost of future joint strike warfare, including:

- Producibility/lean manufacturing
- Precision guided munitions
- Advanced mission planning techniques
- Balance of manned and unmanned[**] concepts

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[*] "Joint Advanced Fighter, envisioned during the BUR as a single airframe that could incorporate both high and low end capability, both carrier and land based operations, supersonic flight and a STOVL variant."

[**] By May 1994, the JAST Program had dropped the unmanned concepts from consideration, deferring this mission application to the existing DoD Joint UAV Office.

Underlying all of this was an intent to eventually design and build strike aircraft; but the near-term focus would be on the requirements and technology "building blocks," thereby allowing specific weapon system development decisions to be made at a later date based on better information regarding threats, force structure decisions, and budgeting.[25] The Navy and Air Force were subsequently asked to make a JAST Program recommendation that would:

- Include ideas for accomplishing technology transition, including prototypes and/or demonstrator aircraft.
- Incorporate the DSB Task Force recommendations
- Identify joint organization and initial lead service (to rotate every three years)
- Include projected funding requirements (5 years with estimates beyond)

Informal monthly status reports were requested, through [redacted] (Director, Tactical Systems, Office of the Under Secretary of Defense (Acquisition & Technology)) and [redacted] (Deputy Under Secretary of Defense for Advanced Technology, and shortly thereafter the Director of DARPA).

The Air Force and Navy acquisition staffs and related organizations were assigned to develop a plan in response to [redacted] tasking. The A/F-X Program Manager, CAPT [redacted] USN, had already briefed the BUR team several times on the A/F-X program, Navy tactical aviation requirements, and related technical issues. As cancellation became increasingly likely, and because the A/F-X program was essentially on hold at that time, CAPT [redacted] volunteered some of his staff to work on formulating plans for the new program. CAPT [redacted] and his Deputy Program Manager (Air Force), Col [redacted] briefed options, plans and progress frequently to the BUR team.[26]

At around that time Gen Mike Loh, Commander of the USAF Air Combat Command (ACC) at Langley AFB, Virginia, tasked Brig Gen George K. Muellner to keep abreast of developments regarding the new program. Brig Gen Muellner was the Director of Requirements at ACC, but had already been selected for a new assignment at the Pentagon as the director for tactical weapons systems in the Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQP). Brig Gen Muellner would later become the first JAST Program Director.[27]

2.2.2 BUR Results

The BUR decisions were formally announced on 1 September 1993 with the following observations regarding theater air forces:

- The four ongoing tactical aircraft programs were unaffordable.
- Existing strike assets would soon reach the end of their service lives, and the A/F-X and MRF filled valid needs.
- The need for MRF was out-year, while the Navy's need for A/F-X or equivalent was immediate.
- A need existed to preserve critical technical and industrial capabilities of the defense industrial base, while drawing down the total production capacity.

Regarding the various combinations of tactical aircraft programs considered for the modernization of theater air forces, the BUR report noted:

> The results indicated that options of similar cost produced relatively equal levels of effectiveness, with no single option standing out as the most cost-effective…. Accordingly, we elected to take a different approach—making only the theater air decisions that need to be made today and preserving the maximum flexibility for future program choices.[28]

With these considerations, the BUR decided to:

- Terminate both the A/F-X and MRF development programs and F-16 production after FY94. These actions would save significant funds both within and beyond the FYDP period.

- Proceed with the F/A-18E/F program. Discontinue F/A-18C/D production as -E/F production begins, to soften the funding "bow wave" associated with -E/F production start.
- Upgrade the F-14 with a limited air-to-surface capability.
- Retire the A-6 fleet by 1998. The F-14 and F/A-18E/F would fill the need for Navy strike aircraft in the near-term.
- Proceed with the F-22 program, but with a reduced quantity. Incorporate a precision ground-attack capability in the F-22 from the outset of production.
- Strengthen supporting capabilities.
  - Standoff weapons for deep strike/hard targets.
  - Improved conventional capabilities for the B-1, B-2, and B-52.
- Begin the JAST program.

The BUR report stated that JAST would focus on common technologies and components in the areas of avionics, propulsion, ground support, munitions, training, and mission planning:

> The technologies pursued under this program [JAST] could be used with any future combat aircraft the nation decides to build. These common technologies account for the bulk of the cost incurred in acquiring and operating aircraft. Different airframes—the chief differentiation between land-based and carrier-based aircraft—are a lesser part of overall aircraft costs. Thus, we are aiming for a combat aircraft that, in terms of cost, is 80 percent "joint," although there may be different airframe silhouettes. We believe this will significantly reduce development and production costs for the next generation of Navy and Air Force aircraft, even if we elect to proceed with different airframes.
>
> The Joint Advanced Strike Technology program will develop several technology demonstrator aircraft to explore different technologies that could be incorporated into future aircraft. From these technology demonstrators, prototype aircraft would then be developed to help choose the next-generation replacement for the A-6, F-14, F-16, and F-111 as they reach the end of their service lives.[29]

2.3 JAST Planning

As the BUR decision to terminate A/F-X and MRF and begin JAST became firm, a JAST transition team was established. This transition team was led by CAPT [redacted] USN, and Col [redacted] USAF, of the A/F-X Program, and Lt Col [redacted] the USAF MRF Program Manager. The ongoing A/F-X Concept Exploration and Development (CE/D) contracts were extended (for the second time), through 17 December 1993, in order to bring activities to a logical closeout and to obtain the A/F-X weapon system contractors' recommendations on high-payoff technologies. These recommendations, together with inputs from MRF and other sources, would be used to formulate a preliminary JAST technology investment strategy. FY93 A/F-X Program Office funding was also extended to 31 December. After that, JAST FY94 funding was expected to be available, and all A/F-X activities not absorbed by JAST would cease.

To summarize the outcome of the previous section, the essential elements of the JAST program as originally conceived were as follows:

- USN and USAF were the principal participants. The position of Program Director would rotate from one department to the other every 3 years.
  - JAST was to support the eventual replacement of aging USN and USAF strike assets: initially the A-6 and F-16; eventually the F-14, A-10, F-111, and others.
- Emphasis was on *affordability.*
  - Defined in terms of *life cycle cost*, not just initial acquisition cost.
  - Drive for *cost commonality*—achieving savings through common components and technologies without trying to force development of a common airframe.

- Pursue technology risk reduction prior to major development decisions.
  - $2 billion investment FY94-99.
  - Could include flight testing of technology or concept demonstrator aircraft.
  - No specific weapon system development until FY00.
- Aggressively pursue acquisition reform—not “business as usual.”

By mid-September 1993, the JAST Program scope had expanded to include another key consideration: participation of the USMC, which was seeking a replacement for their AV-8Bs and F/A-18s. These aircraft, like many Air Force and Navy strike platforms, would reach the end of their service lives early in the 21st century, and a single, high performance STOVL strike fighter could, ideally, replace both. This would reduce the number of different aircraft types in the Navy Department’s inventory, and help the USMC achieve its goal of an all-vertically capable tactical air component (i.e., JAST, the V-22, and helicopters).

The ASTOVL Program had been underway for nearly ten years in various forms, and was under joint DARPA/U.S. Navy management in 1993. However, full funding for flight demonstrations and subsequent development had not yet been identified. The USMC saw JAST as a potential opportunity to develop the ASTOVL concept. For this reason, there was strong USMC representation in JAST planning, and later in the JAST Program Office when established. There was also an explicit consideration—although no formal commitment at this time—of an ASTOVL concept as a candidate for future JAST flight demonstration.

It was recognized that there was much in common between the needs of the Air Force and of the Marine Corps. The Air Force’s first priority was affordability to replace a large number of F-16s reaching the end of service life. This indicated a small, single-engine probably single-crew aircraft. The Marines wanted STOVL, which also meant small and single-engine (since a large twin-engine STOVL fighter was not considered to be technically feasible), and probably single crew, like the AV-8B and F/A-18. Thus, getting the USMC on board early helped steer the JAST Program away from just continuing to pursue an A/F-X concept under a new name, and towards a more affordable range of weapon system concepts.[30]

A preliminary JAST program plan was briefed by CAPT [redacted] to the Chief of Naval Operations (CNO), the Commandant of the Marine Corps (CMC) and the Chief of Staff of the Air Force (CSAF) on 7 September, and to the Secretaries of the Air Force and the Navy on 10 September. OSD was briefed on the preliminary plan and status on 13 September. Following these briefings, at which the overall structure and strategy of the JAST Program was generally agreed to, the transition team concentrated on defining the plan in greater detail. Within the overall JAST planning team, a Science & Technology Transition Team (with co-leads CDR [redacted] USN, from the A/F-X program, and [redacted] from the USAF’s Wright Laboratories) and a Studies & Analysis Transition Team (co-leads CDR [redacted] USN, from the A/F-X program, and [redacted] from the USAF MRF program) were formed. These teams developed a preliminary investment plan and identified critical FY94 and FY95 JAST efforts, including specific technology efforts. On 12 October, the plan was presented to OSD. On 14 October, OSD approved this plan and $50 million was requested from Congress for JAST in FY94.

By that time, the Air Force had been selected to provide the first JAST Program Director; and shortly afterward, then-Brigadier General George K. Muellner was selected. Brig Gen Muellner had only recently begun an assignment in the Pentagon as the director for tactical weapons systems in the Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQP). He served in a dual-hatted capacity as SAF/AQP and unofficial JAST Program Director, until the JAST Program was formally established in January 1994.[31]

Along with the transition teams, Col [redacted] CAPT [redacted] and Brig Gen Muellner selected Maj [redacted] USAF, as the initial JAST Program Security Director. Affordability was a major factor in security planning, as with all other areas, so a traditional approach to security was not seen as feasible. A risk-management approach to security (instead of risk-avoidance) was deemed more effective in reducing

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costs, duplication of efforts, and administrative burdens. The first JAST Security Plan, which provided a strategy for establishing a viable security organization and defined the mission and functions of the JAST Security Directorate, was finalized on 1 November 1993.[32]

Brig Gen Muellner met with the JAST Transition Team on 18 November 1993 to discuss plans and status. Shortly thereafter, he met with Ms. Nora Slatkin, the Navy Acquisition Executive, and [redacted] Under Secretary of Defense (Acquisition), to present JAST Program planning to date, and to solicit their advice. Over the next two months, plans were refined as the Transition Team continued its work and Brig Gen Muellner, Col [redacted] CAPT [redacted] presented the program to key service and OSD executives. The overall program strategy that emerged during this transition period is described in the following sections.

2.3.1 Program Organization and Management

Starting in August 1993, the JAST planning team defined the overall program management concept with lessons learned from the A/F-X and MRF programs. JAST planners surveyed Memoranda of Agreement/Memoranda of Understanding (MOAs/MOUs), joint service plans, and similar documentation from many prior and ongoing joint programs to determine successful strategies and organizational structures for a joint program. The following acquisition programs were studied: Joint Standoff Weapon and Joint Direct Attack Munition (JSOW and JDAM), Advanced Tactical Fighter/Naval Advanced Tactical Fighter (ATF/NATF), Advanced Attack/Fighter (A/F-X), National Aero-Space Plane (NASP), High-speed Anti-Radiation Missile (HARM), Joint Tactical Air-to-Air Missile Office (JTAAMO), Unmanned Aerial Vehicle (UAV) Joint Program Office, and Joint Combat Identification Office (JCIDO).[33, 34]

Drawing on the Packard Commission, the JAST planning team identified multiple opportunities to practice acquisition reform and streamlining, including the following:

- Minimize use of specifications and standards. Do not let specs and standards hinder the affordable application of advanced technology.
- Simplified source selection. Simple, straightforward solicitations, again minimizing the use of detailed specifications.
- Strengthen government/industry partnership. Maximum use of Integrated Product Teams (IPTs), simplified contracting, simplified review and oversight, minimum formal reviews.
- Utilize commercial and government technology.
- Joint program, joint *support* committees (executive committee and advisory group—see below).
- Make the Program Director responsible and accountable. (Evolved into a streamlined reporting chain in which the Program Executive Officer [PEO] level was combined with the Program Director level, and the Program Director/PEO reported directly to the Service Acquisition Executive.)
- Delay implementation of a formal Operational Requirements Document (ORD). Formal program defined only when necessary (i.e., at EMD start).
- Maintain close coordination/interaction with [now Deputy] Under Secretary of Defense (Acquisition Reform).

A draft JAST Charter defining purpose/mission, management authority and responsibility, relationships to other organizations, reporting requirements, and staffing concept for the JAST Program was developed into near-final form by mid-October. According to the Charter, JAST was not an acquisition program, but was to provide proven technologies and validated requirements into subsequent, "offshoot" acquisition programs.[35]

No executive service would be assigned. The two-star position of Program Director would alternate between the Departments of the Air Force and of the Navy approximately every three years, and the Program Director would report directly to the Service Acquisition Executive (SAE) of the opposite Department (i.e., when the PD is Air Force she/he reports to the Navy SAE, and vice versa). The applicable

SAE would then report to the USD(A).* A one-star Deputy Program Director would be of the opposite Department from the Director. While not formally mandated in the JAST Charter, when a Program Director departs, the Deputy Director has historically moved up to fill this position. Although the Directorship rotation was initially set for three years, it has in fact occurred approximately every two years.

A two-star level Advisory Group (later known as the JSF Advisory Group (JAG)) was chartered to advise the JAST Program Director and the Service Acquisition Executives, while an Executive Committee chaired by USD(A) would advise USD(A) on matters related to the JAST Program. The membership of these groups was designed to insure that principal acquisition and requirements officials would be involved in the JAST decision-making process. This would help achieve "buy-in" of the JAST strategy as early as possible, and would prevent surprise issues from surfacing just prior to major program reviews. At the working level, the JAST Program Office interacted with operational advisors and with industry. The overall structure of organizational relationships outside the Program Office is illustrated in Figure 10. (Office symbols are defined in the List of Acronyms at the beginning of this document.)[36, 37]

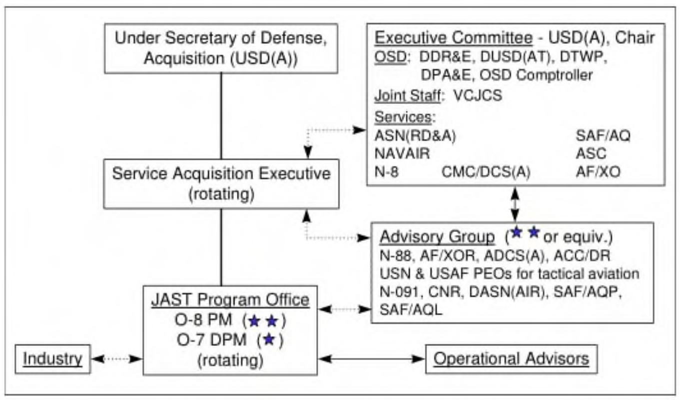

Figure 10: JAST Organizational Relationships[38]

A single Annual Report and Master Plan would be the primary document of the JAST program. This Plan would contain a summary of prior and ongoing efforts, a Technology Roadmap to cover the coming Future (or Five) Year Defense Plan (FYDP) period, and a proposed Investment/Execution Plan, with detailed justification for the coming budget year. Following review by the Executive Committee, the Plan would be provided to Congress and would serve as the JAST Program Director's execution authority. The first Plan was initially due to be completed in February 1994, although this was later extended to May.[39]

A minimum JPO staff (of about 50 people) was envisioned, supported by full-time detachments at the Air Force Aeronautical Systems Center (ASC), Wright-Patterson Air Force Base, Ohio, and at the Naval Air Systems Command located in Arlington, Virginia, (but since moved to Patuxent River, Maryland). The JPO itself would consist primarily of an Executive group, a Requirements group, a Technology group, and a Program Integration group, with responsibilities and organization as shown in Figure 11. At each level, and within each group and subgroup, a personnel balance would be maintained between the participating services.

* At the time JAST was formulated, the chief DoD acquisition executive was the Under Secretary of Defense for Acquisition (USD(A)), an office established by the 1985-86 Packard Commission and the 1986 Goldwater-Nichols Defense Reorganization Act. Shortly after JAST was formed, the office designation was changed to Under Secretary of Defense for Acquisition & Technology (USD(A&T)). In 1999, the name was changed to Acquisition, Technology, and Logistics (USD(AT&L)).

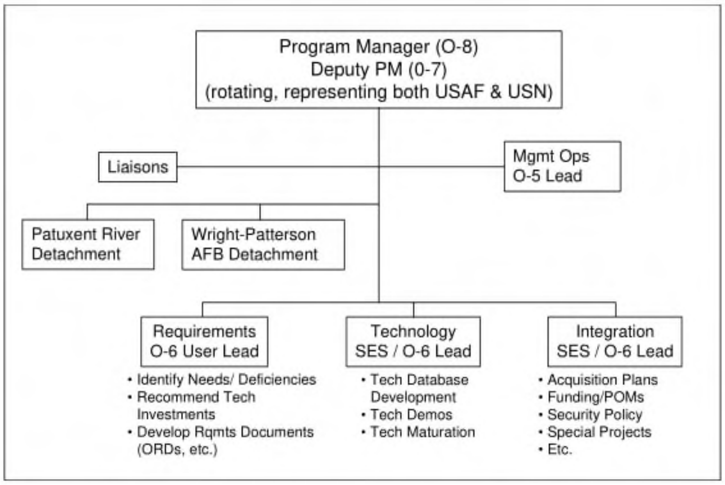

Figure 11: Proposed JAST Program Office Organization as of September 1993[40]

The Requirements group identifies critical operational deficiencies, recommends technology development priorities, and develops—with participating services—operational requirements. Emphasis was to be placed on developing *achievable, affordable* joint-service requirements. The Technology group would review all strike/fighter-related Air Force and Navy Science and Technology (S&T) programs, identify areas of redundancy, recommend jointly funded efforts, and develop technology roadmaps to support major program decisions. The planning activities in these areas are described more fully in the following two sections. The Program Integration group was primarily intended to handle programmatic matters and to help integrate the efforts of the Requirements and Technology groups.

2.3.2 Requirements

One area, open to wide interpretation initially, but clarified quickly in the planning process, was the degree of emphasis that JAST would place on operational requirements. (b)(6) [redacted] original memo had stated that JAST should "focus on key technologies to meet future joint operational requirements while reducing cost and risk." However, to do that, the "future joint operational requirements" would have to be developed in concert with the technologies, towards a common aim of affordable warfighting capability.

The 14 July Defense Science Board assessment of the BUR, which essentially laid the foundation for the JAST Program, included comments on how requirements should be approached:

> The limited time available required the BUR team to focus chiefly on a comparison of tactical aircraft as stand alone air warfare assets….
>
> While a great deal of progress has been made in understanding the effectiveness of various alternatives during the past several weeks, more work is needed to fully assess the effects of standoff weapons, SEAD [Suppression of Enemy Air Defenses], and the tradeoffs associated with bombers and TLAM [Tomahawk Land Attack Missile].
>
> The Task Force observes that the tactical air community is not sufficiently well informed about U.S. bomber capability and vice versa. The mutual understanding needs to be improved, so that we can better exploit the synergy of long range bomber and tactical air employed jointly.
>
> We also need a better understanding of the alternatives available to obtain deep strike. Besides longer range for tactical aircraft, we need to consider bombers, shorter range tactical aircraft with buddy refueling… standoff weapons, and TLAM launched from vertical tubes on ships…. Perhaps the most critical issue is to better understand the number and nature of deep strike targets.[41]

While these comments were made in a general sense, and not specifically in connection with the proposed joint-service technology program that became JAST, the underlying principle formed an important part of the JAST approach to requirements: first, future weapons systems should be considered as part of the overall force structure, and not as stand-alone systems; second, requirements should take into account all practical ways of accomplishing any given military objective, not bound by inter-service or even intra-service (e.g., strategic vs. tactical) conventions. When support systems, C^4I systems (Command, Control, Communications, Computers & Intelligence), etc., are taken into account, this methodology becomes the "System of Systems" (SoS) approach that is now widely accepted.

By mid-September, the emerging JAST plan showed requirements analysis, modeling & simulation, and cost-performance trades taking place in parallel with technology demonstrations to support the development of affordable, achievable requirements by the year 2000, the earliest Milestone II decision date for EMD start. Normally, a formal requirements document is approved much earlier in the acquisition process. However, this early commitment to operational requirements can cause very difficult and/or costly technical requirements to be set too early in a program. JAST chose instead to work requirements in parallel with technology and weapon system concept development, allowing operational requirements to be adjusted in response to modeling and simulation, analysis, demonstrations, and affordability considerations. JAST would "focus technology and requirements toward sensible warfighting capabilities."

Over the next few months, the approach was defined in further detail, to include the following elements:

- **Warfighters and technologists together:** Following a major recommendation of the Packard Commission, JAST requirements development would be accomplished by an integrated team of joint-service operational users ("warfighters"), maintainers, and developers/technologists from both government and industry. This would insure that the costs and technical risks associated with proposed operational requirements were understood and continually assessed. The actual requirements would be defined by the services, facilitated by the JPO Requirements group.
- **Affordable, joint-service requirements:** Identify and work to eliminate service-specific "long poles." Avoid past mistakes such as those made in the TFX/F-111 program, which attempted to forcibly merge fundamentally incompatible requirements. Focus technologies to enable joint-service solutions with high levels of cost commonality, but accept differences where there is legitimate reason for them. Always use total system life-cycle cost as the decision criterion—not arbitrary metrics such as parts commonality.
- **A "system of systems" approach:** Look at new strike systems in the context of overall force structure—including alternative strike assets as well as support systems, C^4I systems, etc.
  - Avoid difficult/costly requirements duplicative of other systems.
  - Make appropriate use of available support, e.g., offboard information sources, to reduce cost of new strike systems.
- **Modeling & simulation:** Identify existing deficiencies in strike warfare and examine new concepts and technologies to address those deficiencies using a hierarchy of models and a significant use of simulation.
- **Strategy-to-task-to-technology (STT) analysis:** Use STT analysis, developed by the RAND Corporation, to develop a hierarchy of objectives to establish a framework for top-down thinking. The end product would be a traceable linkage from the highest-level national goals, down to specific weapon system characteristics. Superfluous "requirements" are avoided. Requirements that are developed are defensible because they explicitly support the accomplishment of key operational tasks, which in turn are linked to operational objectives, campaign objectives, etc., all the way up to the most fundamental national goals. Furthermore, STT analysis is not service specific and is well suited to determining which system(s) are best suited to the accomplishment of an objective. Thus STT is well suited to the development of joint operational requirements. The STT process, and the application of it in the

JAST/JSF Program, is discussed in greater detail in Section 3.2, which describes requirements development during the Concept Exploration phase of JAST.

The overall goal would be the development of *affordable, technically feasible, joint-service* requirements. It was estimated that rigorous execution of the STT process would take two years. However, guidance for technology investments would be needed sooner than that. Some acceleration of the process would therefore be necessary to obtain initial results within 12 months of program start. The initial, abbreviated STT study would: (1) concentrate on only one or two of the 11 scenarios contained in the FY93 Defense Planning Guidance (DPG); (2) only include the initial phases of the conflicts; and (3) address only those tactical air warfare assets (with their associated weapons, training systems, etc.) requiring replacement in the 2010-2015 timeframe. This initial STT analysis would then be updated with progressively greater detail in subsequent iterations.

2.3.3 Technology

From the outset, JAST would *not* be a developer of new technology, but rather as a "transition vehicle" for technologies that were already under development in Air Force and/or Navy S&T programs. As such, JAST would be a "customer" for the services' S&T products. As a general rule, technologies being funded in budget categories 6.1 (Basic Research) and 6.2 (Exploratory Development) were considered too immature for JAST investment. Instead, JAST would look to technologies that were already in budget category 6.3a (Advanced Technology Development) to further develop, integrate, and demonstrate, and provide an added focus to bring selected technologies to low risk for an EMD decision in 2000.

S&T programs typically proceed to the point of demonstrating that a technology or concept is workable, but seldom provide extensive application-specific risk reduction. Yet that kind of risk reduction—integration within the framework of an operational weapon system, or testing in a realistic environment for a representative mission—should occur before a weapon system that relies on the new technology enters EMD. As the DSB Task Force noted, "A significant cause of technical problems in EMD is the gap between the technologist's definition of on-the-shelf and the program manager's definition of off-the-shelf. JAST should contribute to maturing technologies… so that EMD starts at a lower level of technical risk with more truly off-the-shelf technology."[42] In serving as a technology transition vehicle, JAST would bridge that gap and take selected technologies to the level of maturity needed for low risk to enter into EMD.

It was envisioned that most JAST technology investment would be in budget category 6.3b, Demonstration/Validation (re-designated 6.4 at around the time JAST was initiated). However, to ensure the ability to accomplish all necessary efforts, JAST would have the latitude to fund efforts across the entire technology development spectrum. Planning and limited studies and analyses were envisioned for FY94, with technology demonstration programs beginning in FY95 and possible flight demonstrator efforts beginning in FY96. In mid-September 1993, the JAST S&T Transition Team established eight technical area sub-teams. These are illustrated in Figure 12.

(b)(4)

[redacted]

Figure 12: JAST Transition Technology Team Organization[43]

The eight functional area teams were informally referred to as “Tiger Teams” during the transition period from A/F-X and MRF to JAST. Six of the teams represented specific technical features or characteristics of the weapon system. The other two represented a broader “-ilities” focus in supportability and producibility. Each technical team had a Washington, D.C., area co-lead and a Wright-Patterson Air Force Base co-lead, plus additional members as shown, including a representative from each of the “-ility” teams. Wright-Patterson personnel on the teams were drawn primarily from the MRF program. In addition to the eight technical teams, there was one administrative team whose function was to build and maintain a database of all relevant S&T projects.

From mid-September through early October, the Tiger Teams developed a preliminary technology investment strategy. The team met with representatives from the Air Force and Navy laboratories, DARPA, and NASA, and surveyed all ongoing strike/fighter-related S&T programs. In addition, seven Key S&T Thrusts had been identified by DoD in 1992 as supporting U.S. warfighters’ most pressing needs. These were: (1) Global Surveillance and Communications; (2) Precision Strike; (3) Air Superiority and Defense; (4) Sea Control and Undersea Superiority; (5) Advanced Land Combat; (6) Synthetic Environments; and (7) Technology for Affordability. Four of these—2, 3, 6, and 7—were considered relevant to JAST, and so the projects under those thrusts were also surveyed for possible inclusion in the JAST S&T database.

From the various sources, promising technologies were identified based on the JAST goals of affordability and commonality, together with warfighters’ priorities articulated in the A/F-X Tentative Operational Requirements Document, and a list of “Top 25 Customer Needs” developed by the MRF program. In addition, technologies were screened by level of maturity. Those technologies that were already mature, and those that were too immature to reach low risk for EMD entry by 2000, were not considered appropriate for JAST direct investment. The teams focused on identifying FY94 study requirements and critical FY95 demonstration program new starts. The initial results of this exercise were incorporated into the JAST plan that was approved by Dr. Deutch on 12 October 1993.

From late October through most of November 1993, the S&T Transition Team held meetings with industry—including airframe, engine, and avionics manufacturers—to obtain their feedback as to what technologies were most promising for next-generation strike warfare systems. The airframe prime

contractors provided inputs based on their work in the A/F-X, MRF and DARPA ASTOVL programs. Industry recommendations generally reinforced the Transition Team's preliminary findings, but also provided some material for adjustment and refinement.[44, 45]

During December, the team concentrated on absorbing and integrating the industry inputs, and formulating a preliminary flight demonstration strategy. No specific flight demonstrator plans were made at this time; however, it was necessary to estimate when a JAST flight demonstrator effort would occur to provide sufficient overall funding profile. It was judged that some technologies would require flight demonstration for a low risk introduction into EMD.

In January and February of 1994, as the JPO was staffed up, the S&T Technology Transition Team provided its findings, preliminary investment strategy, and technology database to the permanent staff of the JAST Technology Maturation Directorate. Out of roughly 1,700 technology projects surveyed, 585 were considered relevant enough to include in the database. The Transition Team had carefully built up a catalog of relevant technology projects. The JPO's task would be to selectively trim down this list and focus on strategies to further develop those technologies offering the highest payoff, in terms of joint strike warfare effectiveness and affordability.[46, 47]

2.3.4 Flight Demonstration of Advanced Concepts and Technologies

Soon after it was publicly announced, JAST was criticized as being unfocused. Some critics labeled the program a "technology hobby shop," while others complained that there were no formal requirements. Aircraft industry representatives expressed concern that if JAST concentrated only on technologies, and neglected airframe development, critical aircraft design team capabilities and expertise would erode. Brig Gen Muellner responded by emphasizing that JAST would specifically lead to one or more aircraft development programs, and that one or more concept demonstrator aircraft would be developed within five years as part of the JAST strategy.

As noted earlier, the DARPA ASTOVL program at that time was entering a Phase II, or Risk Reduction phase, which would include major ground demonstrations. This phase was scheduled to reach completion in mid-FY96, at which point a decision would be made whether to proceed to a Phase III, involving flight demonstrations in late FY99. The ASTOVL decision would depend not only on the level of technical success achieved in Phase II, but also on the level of support from the services. JAST was considered an appropriate avenue for such support, *if* the ASTOVL concept, together with its Conventional Takeoff and Landing (CTOL) variant(s), could meet the needs of not only the Marine Corps but also at least one of the other services. The goals of ASTOVL—to develop a common, affordable strike fighter—as well as the timing, were consistent with the JAST strategy. ASTOVL therefore figured into the JAST planning as a candidate for flight demonstration, with a decision in mid-FY96.

Based on an initial budget estimate of $1.7 to $2.3 billion from FY94-99, it was envisioned that JAST could fund up to two concept demonstrator aircraft projects. These were referred to as "Advanced Aircraft Concept X" and "Concept Y," with the understanding that one of them could be based on the ASTOVL program. In addition, a small number of separate technology flight demonstrations were envisioned. These would naturally be of smaller scope than the Advanced Aircraft Concept Demonstrators, being focused on demonstrating individual technologies rather than total aircraft concepts. Existing testbed aircraft such as the USAF's AFTI F-16 were potential demonstrator test beds.

2.3.5 Emerging "Master Plan"

Based on the emerging plans in each area—program management, requirements development, Tech Mat, and advanced concept demonstration—a preliminary JAST investment strategy evolved. This strategy provided for a relatively steady level of effort in requirements development; "cornerstone technology"

maturation investments peaking at around $200 million in FY97; and a growing level of investment in "emerging technologies," including flight demonstrations, as illustrated in Figure 13:

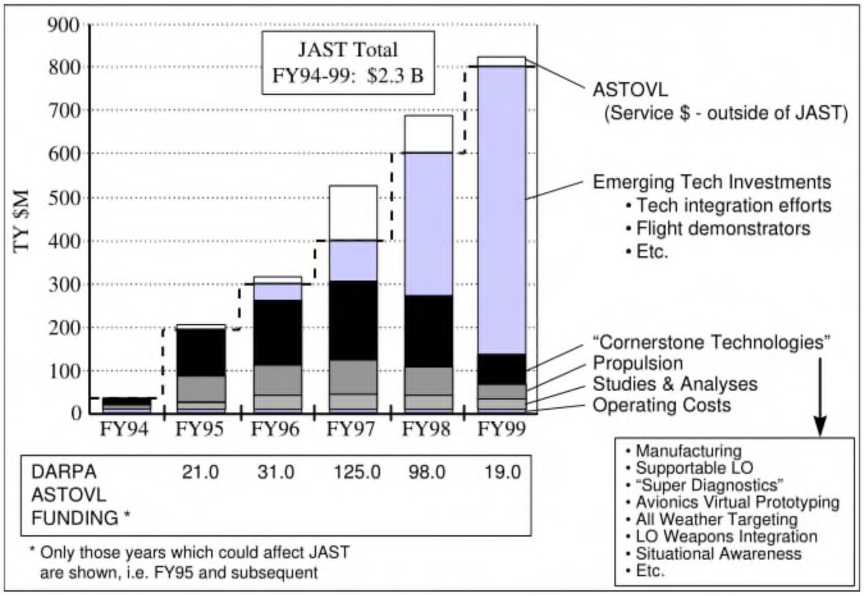

Figure 13: JAST Investment Plan, as of Nov/Dec 1993

The overall JAST program was designed to provide:

- Validated, joint service requirements
- Mature, demonstrated technologies
- Proven operational concepts

These products would support the entry of one or more weapon systems EMD around FY00. The conceptual JAST master plan envisioned at the end of 1993 is illustrated in Figure 14.

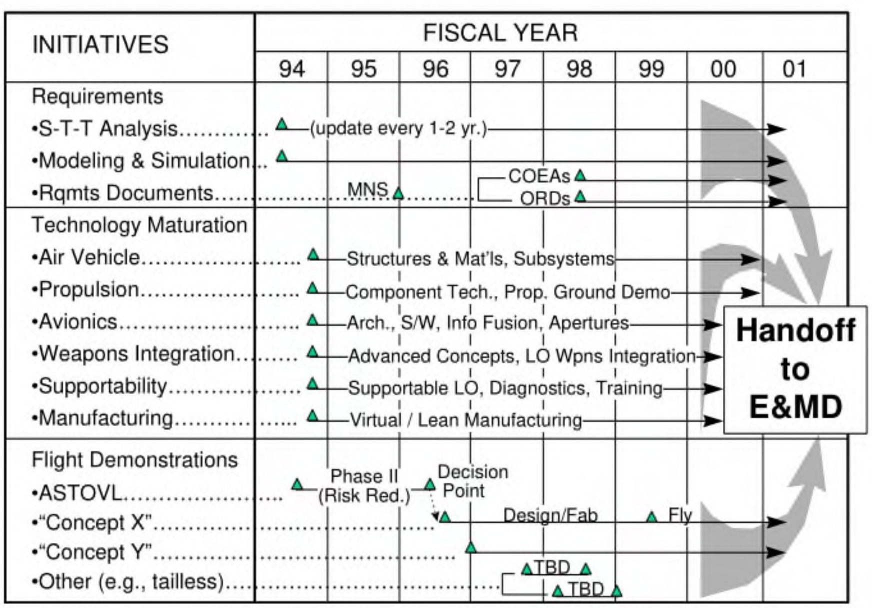

Figure 14: "Emerging JAST Master Plan" (December 1993)

By December 1993, it appeared likely that JAST would receive approximately $30 million for FY94 (already underway). Also in December, JAST received temporary office space on the 4th floor of Crystal Gateway 3, 1215 Jefferson Davis Highway, Arlington, Virginia.* From December 1993 through February 1994, additional JPO staff personnel were assigned.

Since the Program Director, Brig Gen Muellner, was Air Force, the first JAST Deputy Program Director would be Navy or Marine Corps. The Department of the Navy (DoN) named two candidates for the position: RADM Craig E. Steidle, USN (then the F/A-18 Program Manager), and Brig Gen Joseph T. Anderson, USMC (then special assistant to the Director of Tactical Warfare Programs, OUSD(A&T)). RADM Steidle was selected, in part because his strong background in acquisition program management would complement Muellner's operationally-oriented background.[48] (Brig Gen Anderson went on to an assignment as Vice Commander of the Naval Air Systems Command, was promoted to Major General, and at time of this writing is the Commanding General, 1st Marine Air Wing.) Rear Admiral Steidle became the first JAST Deputy Program Director in January 1994. On 27 January 1994, Dr. John M. Deutch, the Under Secretary of Defense (Acquisition), formally established the JAST Program.

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3 *Jane's All The World's Aircraft*, 1992-3 and 1993-4 editions.

4 [redacted] *Joint Strike Fighter (JSF) Program History and Propulsion System Development*, ANSER Draft, 5 September 1997.

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7 [redacted] JSF X-32 Deputy Program Manager, Interviewed by [redacted] 20 October 1997.

8 [redacted] Director, Tactical Systems, OUSD(A), Memorandum for Secretary of the Navy (Attn: Acquisition Executive) and Secretary of the Air Force (Attn: Acquisition Executive), Subject: *Joint Advanced Strike Fighter Technology (JAST) Program*, 21 September 1993.

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10 [redacted] Lt Col USAF, *Point Paper on Technology Prototyping*, SAF/AQT, 20 November 1991.

11 [redacted] *To Fly and Fight: Norms, Institutions, and Fighter Aircraft Procurement in the United States, Russia, and Japan*, Massachusetts Institute of Technology Ph.D. Dissertation, 1994.

12 *Ibid.*

13 "From the Newly Released Bottom-Up Review Report Section V: Modernization Theater Air Forces," *Defense Week*, Vol. 14 No. 41, 18 October 1993.

14 *Jane's All the World's Aircraft*, 1996-7.

15 *F/A-18E/F Milestones*, http://www.boeing.com/defensespace/military/fa18ef/fa18efmilestones.html

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[redacted] "Aspin Not Swayed by Air Force, Navy Fighter Plans," *Defense Week*, Vol. 13, No. 18, 4 May 1992.

18 Twigg, 1994.

19 *Ibid.*

20 [redacted] 1998.

21 [redacted] Chairman, Defense Science Board Task Force on Tactical Aircraft Bottom-Up Review, Memorandum for the Under Secretary of Defense (Acquisition), 14 July 1993.

22 [redacted] "Joint Attack Fighter Eyed to Replace A/F-X, MRF and F-22," *Aviation Week & Space Technology*, 3 May 1993, pp. 21-22.

23 [redacted] July 1993.

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* In September 1994, the Program Office moved to the 3rd floor of Crystal Square 4, 1745 Jefferson Davis Highway, where it remained until September 1998. It is now based in Crystal Gateway 4.

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24 [redacted] "Plans Obscure for Follow-On Aircraft," *Aviation Week & Space Technology*, 9 August 1993, pp. 27-28.
25 [redacted] 1997.
26 *Ibid.*
27 Muellner, George K., Lt Gen USAF, Principal Deputy to the Assistant Secretary of the Air Force (Acquisition), Interviewed by [redacted] 22 January 1998.
28 [redacted] October 1993.
29 *Ibid.*.
30 Muellner, 1998.
31 [redacted] "JAST Funding Faces Skepticism," *Aviation Week and Space Technology*, 25 October 1993, p. 27.
32 *Joint Advanced Strike Technology (JAST) Security Plan*, 1 November 1993.
33 *Joint Advanced Strike Technology (JAST)*, Briefing, 25 August 1993.
34 [redacted] CAPT USN, and Petek, J.M., Col USAF, *Notional Joint Advanced Strike Technology Program*, briefing to Deputy Under Secretary of Defense for Advanced Technology, [redacted] and Director Tactical Systems, [redacted] 13 September 1993.
35 *Charter for the Joint Advanced Strike Technology Program*, Draft Version 2, 14 October 1993.
36 [redacted] January 1994.
37 *Joint Advanced Strike Technology (JAST)*, Briefing, 25 August 1993.
38 *Joint Advanced Strike Technology Program Master Plan*, May 1994.
39 *Charter for the Joint Advanced Strike Technology Program*, as approved by the Deputy Secretary of Defense (John M. Deutch), 12 August 1994.
40 [redacted] September 1993.
41 [redacted] July 1993.
42 *Report of the Defense Science Board Task Force on Joint Advanced Strike Technology (JAST) Program*, Office of the Under Secretary of Defense for Acquisition & Technology, September 1994.
43 JAST Transition Technology Management Team, Memorandum to JAST Technology Functional Area Teams, Subject: *Technology Investment Strategy*, Attch. 1: "Technology IPT," 30 Nov 1993.
44 [redacted] "Pentagon JAST Team Canvasses Industry," *Aviation Week & Space Technology*, 8 November 1993, pp. 71-72.
45 JAST Transition Technology Management Team, Memorandum to JAST Technology Functional Area Teams, Subject: *Technology Investment Strategy*, 30 November 1993.
46 [redacted] Col USAF, JSF Requirements Director, Interviewed by [redacted] 27 February 1998.
47 [redacted] JSF Mission Systems IPT Support (Veda, Inc), Interviewed by [redacted] 23 October 1997.
48 Muellner, 1998.

3 Concept Exploration Phase (CE)

The Concept Exploration phase of the JAST Program nominally covered the period from the formal establishment of the program on 27 January 1994, through the completion of initial Concept Exploration studies by industry in December 1994. Because JAST was not formally then an "acquisition program," "phases" do not correspond to formal milestone decisions, but rather to key events. The Concept Exploration phase would focus on the "exploration of innovative concepts/technologies to reduce the cost for accomplishment of joint strike warfare while maintaining U.S. combat capability."[1]

3.1 Program Management

The organization of the JPO was determined during the transition period, primarily in December 1993. Many Transition Team members, and some personnel on temporary assignment from other organizations, assumed permanent JPO positions. After the program was formally established, a concerted effort was made to fill vacant positions as rapidly as possible. The JPO, in early 1994, is illustrated in Figure 15.

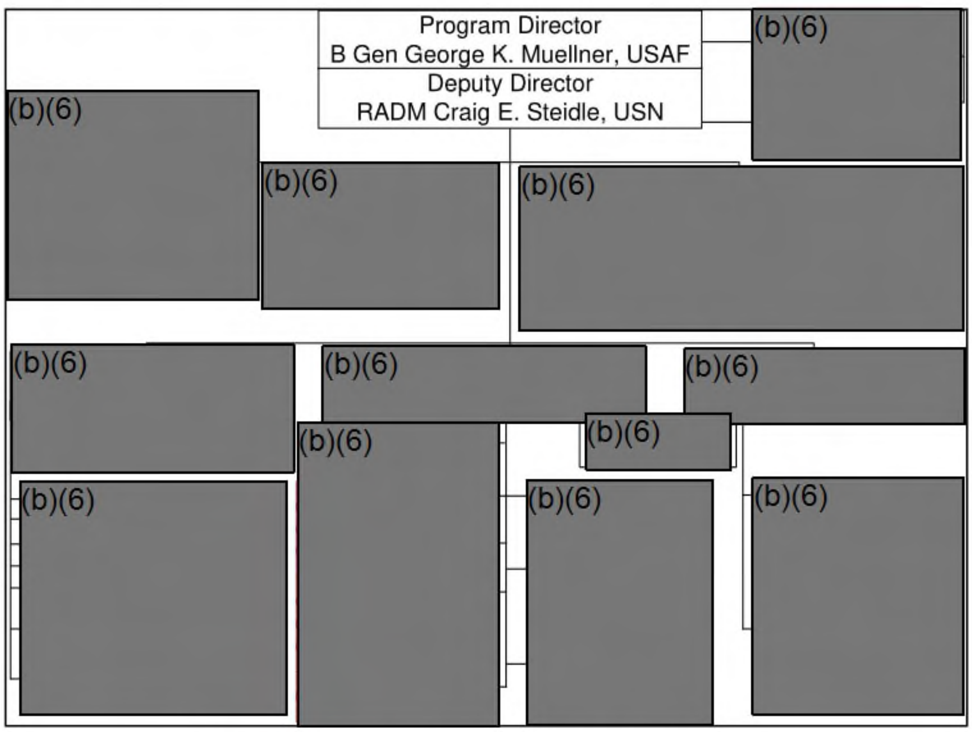

Figure 15: JAST Program Office (early 1994)

The Vision of the JAST Program, as established in January 1994, was: "A joint services' team creating the building blocks for affordable, successful development of next generation strike weapon systems." The Vision, and the structure, organization, authority and operating procedures of the JAST Program—essentially as described in the previous chapter—were set forth in the JAST Charter, developed during the transition planning period of late 1993.

The Charter was signed by Dr. Sheila E. Widnall, Secretary of the Air Force, on 30 March; by Mr. John H. Dalton, Secretary of the Navy, on 26 May; and by Dr. John M. Deutch, then Deputy Secretary of Defense, on 12 August 1994. Dr. Deutch had become Deputy Secretary of Defense in early 1994, and his previous position as USD(A) was temporarily filled by the Principal Deputy, Mr. Noel Longuemare. Later that year, (b)(6) [redacted] became the new Under Secretary, and at his request the office designation

was changed to Under Secretary of Defense (Acquisition & Technology) (USD(A&T)). [redacted] was previously Chairman of the Defense Science Board, as noted earlier.

The FY94 Defense Appropriation Act provided $29.7 million as initial funding for the JAST Program. While future year funding would come equally from the Air Force and the Navy, all FY94 funding came from the Navy via the recently cancelled A/F-X program element. This was a matter of necessity, since JAST had arrived too late to receive consideration in either Department's FY94 budget planning. The top-level JAST budget for FY94 through FY99, as reflected in the FY95 President's Budget Request (submitted in February 1994), is as shown in Table 1 below. However, the FY94 money would not be released to the program until a JAST Master Plan was provided to Congress. As noted previously, the Master Plan was the principal document by which JAST would report to OSD and Congress, and would then serve as the Program Director's execution authority.

Table 1: JAST Funding in FY95 President's Budget Request

	FY94	**FY95**	**FY96**	**FY97**	**FY98**	**FY99**
Navy	29.7	100.0	151.6	202.8	305.4	409.3
Air Force	-	101.4	152.0	200.9	305.8	415.7
Total	29.7	201.4	303.6	403.7	611.2	825.0

During the first several months of the program, many briefings were presented to congressional committees and staff members to communicate the program's objectives and strategies. Brig Gen Muellner, RADM Steidle and Col [redacted] (who, as JAST Requirements Director, was the senior warfighter in the program, as well as the senior Marine officer), always made these presentations together to communicate a cooperative, joint-service effort to their audiences. Additionally, Brig Gen Muellner was acutely aware of the need to prove, not only to Congress but also to industry, that JAST was "real," that it was worth getting involved with, and that it represented a new program and a new way of doing business—not just A/F-X and the Multi-Role Fighter (MRF) continuing under a joint banner. To initiate communication to industry, the first JAST Industry Day was held on 25 February 1994 at the Defense Systems Management College (DSMC), Fort Belvoir, Virginia, as a forum for familiarizing industry representatives with JAST vision and goals. It provided industry with a way of getting involved with JAST as soon as possible.[2, 3]

The first tasks for the new Program Office were therefore to solicit proposals and award contracts to industry, and to produce a Master Plan.

3.1.1 Broad Agency Announcement (BAA) 94-1 Solicitation and Contract Award

[redacted] former A/F-X Deputy Program Manager for Test & Evaluation (T&E), was charged with initiating the JAST Concept Exploration studies. This entailed preparing and releasing a solicitation, evaluating industry proposals, and awarding contracts. [redacted] was supported by an Integrated Product Team (IPT) consisting of personnel from the JPO, the Naval Air Systems Command (NAVAIR), Wright Laboratories, and the Air Force Aeronautical Systems Center (ASC). This team met on 19 January 1994. Their goal was to release the solicitation prior to the JAST Industry Day on 25 February. To achieve this accelerated schedule, three significant streamlining actions were taken: (1) use of a Broad Agency Announcement (BAA) for the solicitation; (2) electronic submission and evaluation of industry proposals; and (3) the use of Short Form Research Contracts.

The more common form of solicitation to industry is the Request for Proposals (RFP). However, an RFP entails many legal and administrative requirements. A more streamlined, and less restrictive, method is the BAA. In particular, a BAA has the following advantages:

- Abbreviated solicitation and proposals
- A single contractor may submit multiple proposals and receive multiple awards

- Variable number of contract awards based on the quality of the proposals received
- Partial awards (government chooses to procure specific portions of a proposal)

There are also limitations in the ways a BAA can be used. A BAA states needs in the most basic form, and *may not*:

- Restrict any approach
- Segment or scope the work to be performed
- Be related to development of a specific system or hardware solution

Because of these restrictions, BAAs are seldom used in formal weapons system development and acquisition, and consequently most acquisition officials have little experience with them. Nevertheless, the BAA was ideally suited to the purposes of the JAST Concept Exploration phase, which was to obtain a wide range of innovative ideas and concepts for reducing the costs of joint strike warfare.

On 24 January 1994, a preliminary plan was presented to Brig Gen Muellner and RADM Steidle. At this meeting the use of the BAA approach was approved, and it was decided to execute the source selection in a "paperless" environment. Furthermore, it was decided to use NAVAIR as the Contracting Agency. RADM Steidle made arrangements for the assignment of Mr. Patrick McLaughlin, a NAVAIR contracting officer with past experience with BAAs in the Army. He had also served under then-CAPT Steidle as Principal Contracting Officer for the F/A-18E/F and F414 EMD contracts. Mr. McLaughlin subsequently became the Principal Contracting Officer for JAST, and continued to serve in that capacity through the Concept Demonstration Phase source selection and contract award (Section 4.5.1).[4]

The initial JAST BAA, termed BAA 94-1 moved very quickly. The solicitation was drafted and staffed during late January and early February and was released by the NAVAIR Assistant Commander for Contracts on 17 February. It appeared in the *Commerce Business Daily* (*CBD*) approximately one week before the first JAST Industry Day. A purpose statement, extracted from this announcement, is reproduced below. (The entire BAA-1 was approximately three pages in length and is reproduced in Appendix B.)

> The purpose of this Broad Agency Announcement (BAA) is to obtain studies aimed towards identifying System Concepts with high payoff potential (e.g. lower cost). Proposed studies should include innovative concepts, and/or application of advanced technologies, aimed at reducing the cost of strike warfare, while maintaining U.S. technological superiority in combat. Proposed concept studies may address the full spectrum of strike warfare systems, combinations of systems, or specific elements of strike warfare, such as advanced aircraft and weapons concepts, manned and unmanned concepts, mission planning or strike warfare command and control. Proposals which address application of advanced technologies should place primary emphasis on reducing the life cycle cost of strike warfare systems with stress on the major elements of system cost (i.e., manufacturing (unit fly away cost/decoupled from volume) and operations and support costs (to include training)) applicable to airframe, avionics and propulsion. Studies should consider differences in operating and support environment between services, approaches to maximize system commonality (e.g. modularity) and promote joint service utilization.[5]

An "Executive Day" was held in early February 1994, with chief executives from 50 of the nation's leading defense contractors in attendance, plus government acquisition principals including Dr. John Deutch (USD(A)), Mr. Noel Longuemare (Principal Deputy USD(A)), and Ms. Nora Slatkin (Navy Acquisition Executive). At this briefing, Brig Gen Muellner announced his commitment to implement paperless acquisition processes, beginning with the BAA 94-1 source selection. Shortly afterward, at the JAST Industry Day on 25 February, 207 industry representatives received briefings on the JAST Mission, Strategy-to-Task-to-Technology analysis, other JAST processes and initiatives, the JAST organization, and key products expected from the program.[6]

A one-page amendment to BAA 94-1, which clarified the evaluation criteria, was published in the *CBD* on 15 March. BAA 94-1 proposals were due on 15 April; 154 proposals were actually received, submitted on computer diskette (with one paper copy for backup). Ten BAA 94-1 voting evaluators (supported as

necessary by additional cost and technical experts) used a Local Area Network (LAN) of personal computers, with database software and electronic evaluation worksheets, to conduct the source selection in two weeks. Contract award was accomplished in one additional week. Twelve Concept Exploration Phase contracts totaling $10.7M were awarded on 6 May 1994. These are listed in Table 2:

Table 2: BAA 94-1 Contracts

Overall Weapon System Concept Exploration		
Modular Multi-Service Airframe	Boeing Defense & Space	$2.2 M
Leveraging JAST Affordability	Lockheed	$2.0 M
Joint Strike Warfare Concept	McDonnell Douglas	$1.7 M
Joint Strike Aircraft Concept Exploration	Northrop Grumman	$0.7 M
JAST Affordability Studies	Northrop Grumman	$0.3 M
Note: The two Northrop Grumman contracts were awarded separately to Northrop and Grumman, respectively. Northrop acquired Grumman shortly afterward and the two efforts were then managed as one.		
Avionics		
Affordable Next Generation Avionics	Honeywell	$0.1 M
Sensor Integration Trade Studies & Architecture	Litton Amecom	$0.5 M
Affordable off-board architecture	McDonnell Douglas	$0.6 M
Weapons Integration		
Cost-effective Weapons Carriage Options	Hughes Missiles	$0.3 M
Affordable Weapon Integration Study	McDonnell Douglas	$0.7 M
Virtual Strike Warfare Environments		
Virtual Strike Environment Architecture	Cambridge Research	$0.8 M
Virtual Strike Environment	Northrop Grumman	$0.5 M

The BAA-1 contracts themselves were paper rather than electronic. However, the use of Short Form Research Contracts allowed the average contract length to be 12 pages, rather than the typical 100 pages. Short Form Research Contracts are normally used for research contracts with educational institutions or other nonprofit organizations. However, NAVAIR, as contracting agency, requested a Class Deviation to the Defense Acquisition Regulations, to permit JAST to use Short Form Research Contracts for Concept Exploration Phase studies. The request was endorsed by the Office of the Assistant Secretary of the Navy (Research, Development and Acquisition) (ASN(RD&A)) and approved by the Department of Defense (DoD) Acquisition Regulatory Council.

This was a pioneering effort in the field of electronic source selection. However, the source selection team did not try to do "everything at once" (for example, the paper contracts). Rather, their approach was evolutionary. Lessons learned were recorded and then used to improve the process. In subsequent procurements, additional improvements were implemented without jeopardizing the integrity of the source selection process. In this manner, the electronic source selection capability advanced without any serious "glitches" or excessive risk to the program. Documentation, software, and lessons learned were also made available throughout DoD and other government agencies.

In June 1995, the individuals responsible for the BAA 94-1 source selection effort received the Navy Procurement Competition Award. The total time from the first BAA 94-1 planning meeting, through contract award, was less than four months. For comparison, typical contract solicitations often take a year or more from initial planning through contract award. The specific contracted studies are discussed later in this chapter; the electronic source selection process is discussed further in Chapter 8.[7, 8, 9]

3.1.2 1994 JAST Master Plan

As noted above, FY94 funding was contingent upon the release of the first JAST Master Plan. This requirement aside, it was necessary to develop and to communicate, even to the personnel within the Program Office, what JAST intended to do: in essence, to transform JAST from a “vision in Brig Gen Muellner’s mind” into an organization that could accomplish this vision.

Each JAST Directorate (i.e., Requirements, Technology Maturation, etc.) developed plans, in support of the overall JAST strategy, for developing validated requirements, mature technologies, and proven operational concepts by the year 2000. This in turn would provide for one or more weapons systems to enter EMD at that time, affordably and with an acceptable level of risk. In support of this goal, the period from 1994 to 2000 was divided into three phases: Concept Exploration (FY94), Concept Development (FY95-96), and Concept Demonstration (FY97-00). Essential features and products of each phase are summarized in Table 3.

Table 3: JAST Program Phases

Phase:	Concept Exploration	Concept Development	Concept Demonstration
Timeframe:	FY94	FY95-96	FY97-00
Principal Activities:	Planning/Studies	Design/ Development	Integration/ Demonstration
# of Concepts:	“Many”	“Several”	“Few”
Key Products:	• Technology “catalog” • Initial STT analysis • Program plans	• Initial tech demos • Refined STT analysis • Mission Needs Statement (MNS) or equivalent	• Proven technologies, components, & concepts • Advanced aircraft concept demonstrations • Validated Operational Requirements Document(s) (ORD)

To place the focus on life cycle affordability, and to provide a uniform basis for trade studies and comparisons, JAST adopted a hypothetical Life Cycle Cost (LCC) baseline. The baseline, illustrated in Figure 16, was developed from historical data, with emphasis on recent programs including the F-22, B-2, F-15E, F/A-18C/D, and F/A-18E/F.

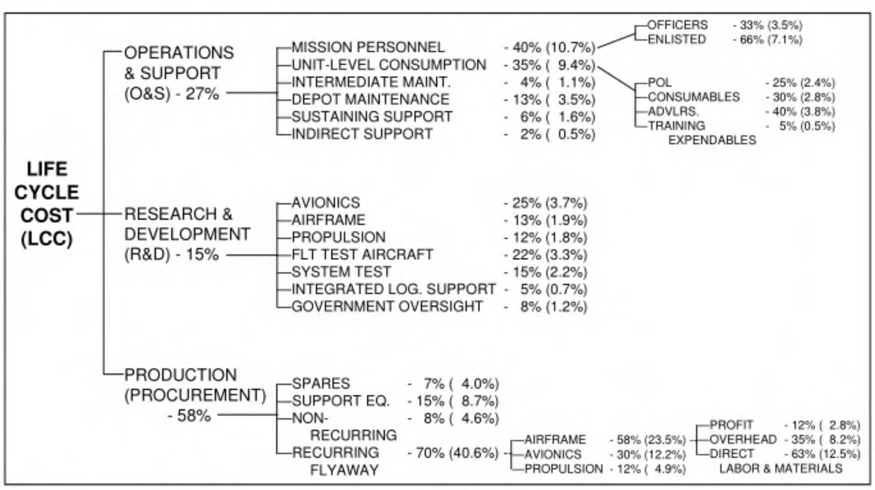

Figure 16: JAST Life Cycle Cost (LCC) Baseline as of 1994[10]

The effort to build the JAST Master Plan began around mid-March 1994. RADM Steidle coordinated the development of the 70-page document, which took about two months of intensive effort. However, upon release in early May, it proceeded smoothly up the reporting chain to ASN/RD&A, USD(A&T), and ultimately to Congress. Release of the Master Plan to Congress coincided closely with the BAA 94-1 contract awards, thereby ensuring FY94 funding availability for those efforts and other JAST Program activities.

The Master Plan set forth the JAST Program structure (as defined in the Charter), top level budget for FY94 through FY99 with specific FY94 and FY95 investment plans (essentially as developed by the JAST Transition Team), a description of the JAST approach to affordability, and the plans of each JAST Directorate. The specific FY94 efforts and accomplishments in the areas of Requirements, Technology Maturation, and Weapon System Concept Exploration, are described in sections 3.2 to 3.4.

3.1.3 Program Protection & Security

With the establishment of the JAST Program, it was recognized that an on-site security office would be required to ensure sensitive information was adequately protected. In keeping with the affordability focus of JAST, the program protection function was also tasked to "ensure security costs and administrative requirements are reduced to the minimum required to protect the critical enabling technologies handled by the JAST Program Office."[11] From the onset, the desire to keep the Program Office small was especially applied to the security effort, with only three government billets allocated. The rest of the effort was to be handled by contractor support services.[12]

The Program Protection and Security Directorate (SC), headed by Maj (later-Lt Col) (b)(6) [redacted] USAF, was therefore created to establish, implement, and maintain a security program that balanced the cost and risk of protecting the critical aspects of the JAST Program, its systems and its underlying technologies. A formalized process was established to identify, assess, validate and prioritize security requirements *prior* to the expenditure of significant resources for security protection; this was a unique approach—to conduct trade studies balancing cost and risk.[13]

For example, security team members were heavily involved in identifying the security specification for the facility in Crystal Square 4 that housed the JAST/JSF Program Office from September 1994 to September 1998. Applying risk management principles, the SC team had a significant impact on the early facility design. This up-front involvement substantially reduced build-out costs.

The JAST Life Cycle Cost model also needed to include the cost of security. However, it soon became obvious that the contractors had never thought of it in those terms before. In previous programs, requirements had been levied on the program, and the contractor had to implement them. When asked for various methods of doing business, they didn't have a cost model, so the program started an in-house model that was tied to the technology being developed. According to Newsham, the intent was to:

> "cost-out" various security options and use the model to develop a security design unique to JAST, not simply accept a PSD [Program Security Directive] and an SCG [Security Classification Guide] and being told to implement by persons who did not own the process and had to bear no responsibility for cost, schedule or performance….We realized how bad the situation was during source selection when most bidders couldn't provide even the most basic rationale for their security charges.[14]

Therefore, Security began developing a life cycle cost model. This development has continued into the subsequent phases.

3.2 Requirements

3.2.1 Mission and Organization

The purpose of the JAST Requirements (RQ) Directorate is to facilitate the development of affordable, achievable, joint-service strike weapons system requirements. The initial JAST Requirements staff consisted of an operator (pilot) and a maintainer/logistician from each participating service, plus an intelligence/ threat analyst, under the direction of Col [redacted] USMC, a former AV-8B test pilot, acquisition officer, and Group Commander. His deputy was then-Lt Col [redacted] USAF, a former F-15 pilot and requirements officer; Faye also served as the Air Force operator in RQ.

JAST RQ interacted with the operational communities primarily through two groups: the Force Process Team (FPT) and the Operational Advisory Group (OAG). The FPT was established to represent the end users in the JAST requirements process. Membership initially consisted of about 70 operators and maintainers, representing most of the major operational commands of the three U.S. services. The FPT met relatively infrequently (several times a year), but often enough to ensure that the full tactical expertise of the three services were represented in assessing deficiencies and needs in the Strike Warfare mission area. The FPT formed the backbone of JAST/JSF Modeling, Simulation & Analysis (MS&A) activities.

The smaller OAG essentially functioned as the "core" of the FPT, and met more frequently. It was made up of representatives specifically from the requirements organizations of the three services (USAF ACC/DR, USN OPNAV/N88, and HQ USMC/APW). While the JAST RQ Directorate was responsible for facilitating the overall requirements process, establishing requirements was the responsibility of the OAG.

3.2.2 JAST Modeling, Simulation & Analysis (MS&A) Vision

The original JAST MS&A vision, as set forth in the 1994 JAST Master Plan, is shown in Figure 17.

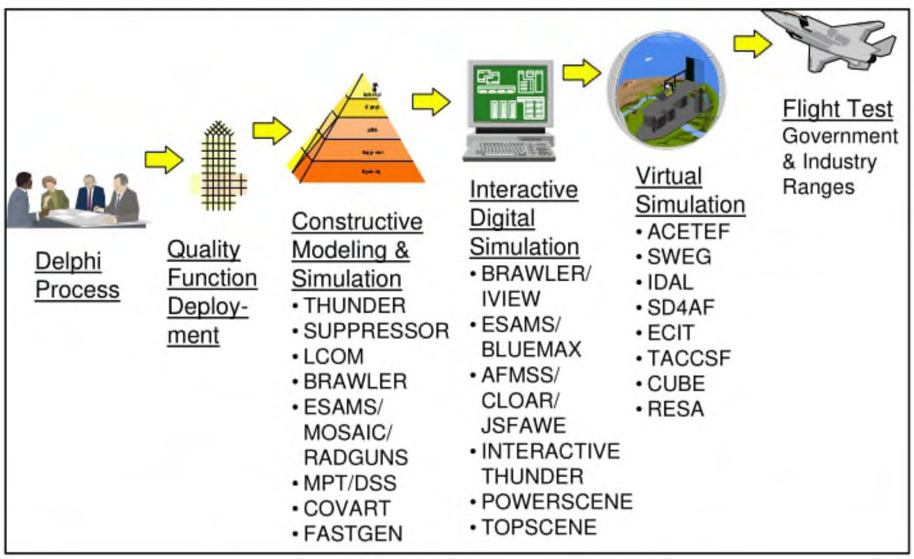

Figure 17: JAST MS&A Vision, 1994

- **The "Delphi process"** is simply the first step of getting the multidisciplinary experts from diverse communities to define common terms of reference and share insights.
- **Quality function deployment (QFD)** is a group-oriented process for defining, qualitatively, relationships between objectives and tasks. JAST used QFD in the context of the hierarchical STT analysis. STT and QFD are described in the following two sections (3.2.3 and 3.2.4).

- **Constructive modeling & simulation (CM&S)** works on the basis of "data in, data out." The only opportunity for user interface is via input data files, which are prepared in advance. CM&S is the easiest and cheapest way to perform a large number of M&S iterations, and thereby generate a statistically significant data sample for modeling stochastic (random) processes, or to perform quantitative trade studies.

- **Interactive digital simulation (IDS)** provides opportunities for human decisions, but not on a real-time basis. Input and output are still primarily in the form of data, rather than realistic sensory stimulation and response.

- **Virtual simulation (VS)** places the human(s) in a simulated operational environment where decisions are made in real-time. VS is the most expensive form of simulation, but is an excellent way (short of building and testing the actual hardware) to provide users with a "man-in-loop" opportunity to evaluate candidate systems.

- **Flight test** is the final step, and may take the form of subsystem demonstrations on test aircraft, or ultimately JAST weapon system concept demonstrators or prototypes.

Each successive step in this MS&A progression not only demands progressively more resources, but also provides a higher level of fidelity and/or richness of information and insight. JAST recognized the deficiencies in existing M&S capabilities, and planned investments to address those deficiencies. The initial plan was: (1) to identify leveraging operational tasks, weapons system attributes, and enabling technologies using QFD analysis; (2) to perform initial evaluation of a broad range of concepts using a "core set" of existing CM&S tools; and (3) to build on the results with progressively more advanced IDS and ultimately VS efforts in conjunction with a narrowing-down of the number of concepts under consideration.[15]

Modeling activities can also be categorized by the breadth or scope of what is being modeled. At the lowest level, engineering analysis is used to determine the *performance* of individual components, subsystems, and systems. At the next level, the *effectiveness* of one (or a few) systems in combat is evaluated using engagement or mission level modeling. The highest level is used to determine the *outcome* of an entire campaign. This hierarchy of M&S tools, and corresponding products, is represented in Figure 18.

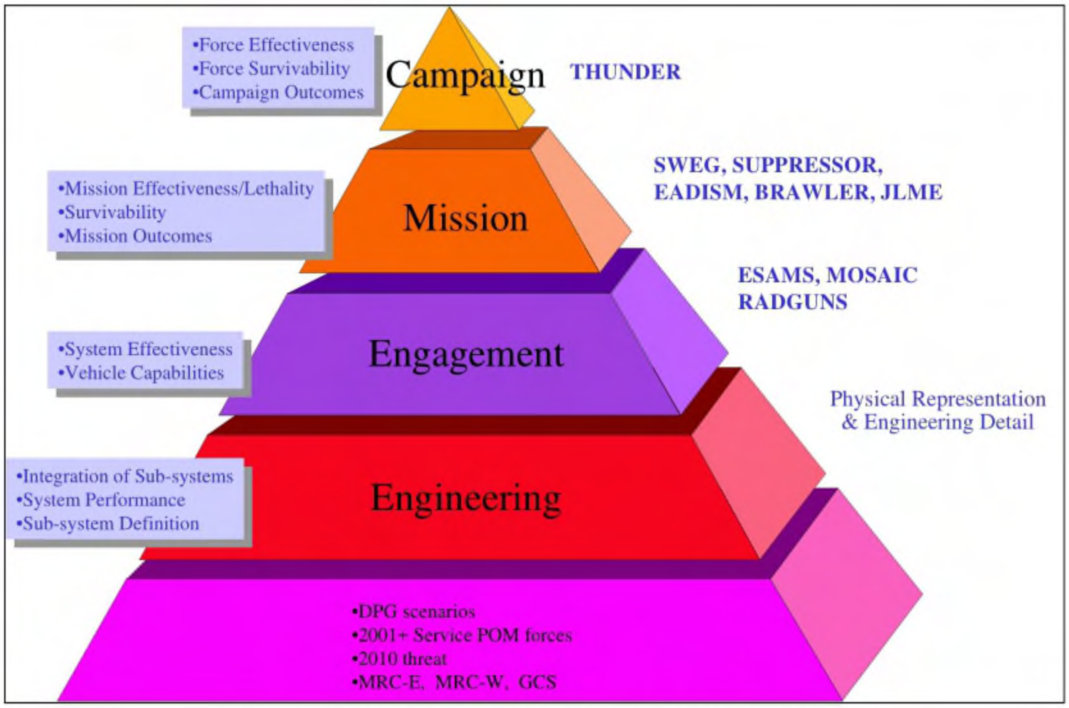

Figure 18: Modeling and Simulation Hierarchy

The shape of a pyramid reflects the number of modeling tools available at each level. Numerous tools exist at the engineering level, where many individual, specialized tools model many different physical processes, in such areas as aerodynamics, thermodynamics, structural loads and deflections, electromagnetic scattering, engine performance, and avionics performance, to name a few. Working up from the base of the pyramid, physical processes, weapons system characteristics, and ultimately the weapons systems themselves are progressively aggregated. Therefore, a smaller number of distinct models are available. Moreover, the models become more complex at progressively higher levels of aggregation.

Traditionally, ASC and NAVAIR performed extensive engineering modeling and analysis during the conceptual stages of new aircraft programs. However, the JAST philosophy was to leave the engineering modeling to the industry where design of weapons systems and subsystems occur.

Some early JAST engagement-level simulation was performed, using constructive models such as ESAMS (a surface-to-air missile model) and RADGUNS (a radar-guided anti-aircraft gun model) to understand the appropriate "trade space" (i.e., the ranges of attributes that should be looked at for future strike warfare weapons systems). Full mission-level simulation is considerably more complicated than engagement-level, and was not performed during the initial phases of the JAST Program. However, preliminary exploration of possible full-mission, virtual strike warfare simulation architectures was conducted under two of the BAA 94-1 contracts: Virtual Strike Environment Architecture (Cambridge Research, $0.8 million) and Virtual Strike Environment (Northrop Grumman, $0.5 million). These early studies laid the groundwork for the major, multi-year Virtual Strike Warfare Environment (VSWE) effort.

Most of the M&S accomplished by the JAST FPT in the early phases of the program were at the campaign level, using the DoD campaign model, Thunder. Thunder is the campaign model used by the Air Force, and to some extent by other services as well, since the 1980s. It is primarily a constructive model, although JAST added some levels of interactive capability by stopping the simulation at specified points and allowing the warfighters to more fully evaluate certain information (that would typically be available to commanders in an actual conflict) and make decisions to adjust target priorities and force employment.

3.2.3 Strategy-to-Task-to-Technology Process

The STT method forms the core of the JAST requirements analysis process. STT was developed at RAND during the late 1980s by Lt Gen Glenn Kent, USAF (Ret.), a former Director of the Air Force Center for Studies & Analyses (AF/SA). STT uses a hierarchy of objectives to establish a framework for top-down thinking, as illustrated in Figure 19.

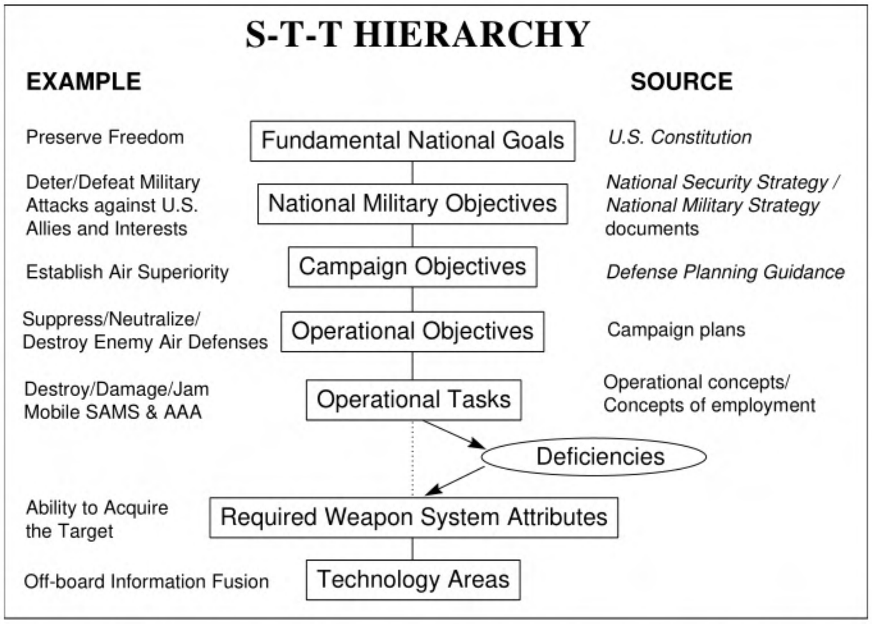

Figure 19: Strategy-to-Task-to-Technology Hierarchy of Objectives

Each level starts with a set of goals ("what" must be accomplished), and develops strategies for "how" to accomplish those goals. The strategies or "hows" at one level then become the goals or "whats" for the next level down. STT had been used in the MRF and A/F-X programs. JAST did not re-invent the entire hierarchy, but utilized the structure and databases developed in those earlier programs. In addition, the topmost levels of the hierarchy—from National Goals to Campaign Objectives—were already set forth in the FY93 Defense Planning Guidance (DPG) for the 2010 timeframe. JAST proceeded from these established objectives to more detailed levels to determine: (1) leveraging operational tasks; (2) existing deficiencies in the performance of those tasks; and (3) high payoff technologies for addressing those deficiencies in the strike warfare environment expected in the year 2010.[16]

3.2.4 Quality Function Deployment (QFD)

QFD consists of a series of matrices. On the vertical axis of a matrix are the objectives, or the "whats" that must be accomplished. On the horizontal axis are the "hows," or the available means to accomplish the stated objectives. The "whats" and the "hows" of the matrix are considered in a pairwise manner to establish a numerical linkage for each pair. These numbers are indicative of the estimated contribution of each "how toward the accomplishment of each "what." The numbers are determined by a vote of participants, who should represent all relevant areas of expertise, according to the following scale:

None 0 Weak: 1 Moderate: 3 Strong: 9

Additionally, each objective has a weighting factor that denotes its importance relative to other objectives. The importance of each "how" in accomplishing each objective is multiplied by the weighting factor for that objective; the weighted contributions are then added to produce an aggregate score of the total value of a "how." These aggregate scores, called Technical Importance (TI) ratings, flow down as

weighting factors in the next level matrix where the "hows" of an old matrix become the "whats" of the new matrix. A notional example of two QFD matrices is illustrated in Figure 20.

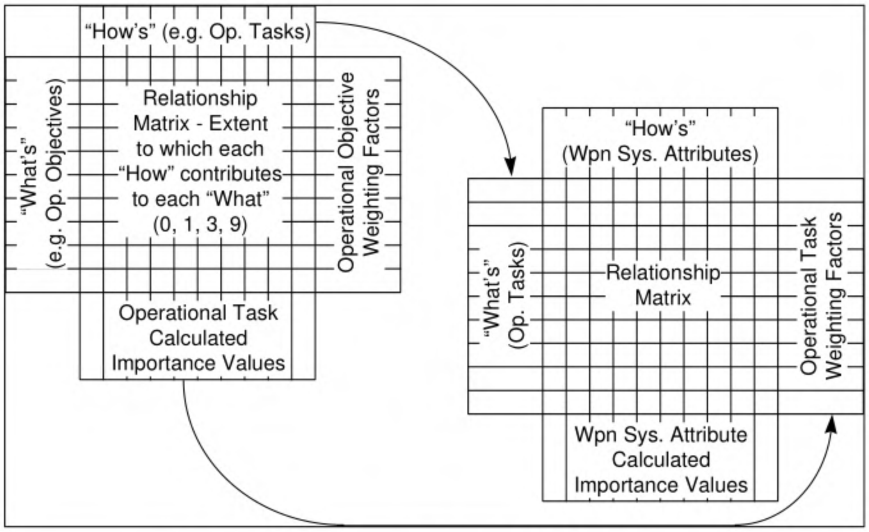

Figure 20: Representative QFD Matrices

3.2.5 Force Process Team (FPT) Activities and Events

The first FPT meeting was held in May 1994 at Naval Air Station (NAS), Fallon, Nevada to introduce team members to the purpose and philosophy of the JAST program, and plan for the forthcoming M&S exercises. FPT meeting activities included defining campaign objectives and flight profiles for each type of mission or task that would be modeled. Bringing together FPT members with their very diverse backgrounds was an important step toward achieving a common understanding of what they would need to do.

The next FPT meeting took place in June 1994 at NAS Miramar, California. This was a major QFD exercise in which the first two matrices, Matrix A and Matrix B, were established and scored. Matrix A linked Operational Objectives to Campaign Objectives. This matrix described the relative contribution of each Operational Objective (e.g., "Defeat lead units of advancing armies" or "Defeat reserve forces") to each Campaign Objective (e.g., "Defeat advancing armies"). Because Matrix A was the starting point for the QFD "Flowdown," the Campaign Objective weighting factors were assigned based on the professional judgment of the FPT members. The Operational Objectives were then scored according to their contributions to the weighted Campaign Objectives. These scores became the Operational Objective weighting factors in Matrix B, which linked Operational Tasks (e.g., "Destroy tanks") to the Operational Objectives.

On 21-23 June 1994, in Arlington, Virginia, the JAST Program Integration & Analysis and Technology Maturation Directorates participated along with the Requirements Directorate in defining the remaining matrices. Matrix C linked Weapons System Attributes to the Operational Tasks, and Matrix D linked Technologies to Attributes—or, more specifically, potential *advances* in technology to potential *improvements* in Weapons System Attributes, relative to what can be achieved with current technology. Matrix E linked technologies to affordability using two criteria: cost to mature each technology, and potential LCC payoff of each technology.

At the third FPT meeting, at Eglin AFB, Florida, in July, the scores in the first two QFD matrices were presented, reviewed, and given the final "sanity check." Based on preliminary assessment of these results, it was decided to explicitly break out logistics tasks and attributes to enhance their visibility in the process.

A "parallel track" for linking logistics tasks and attributes was then established, and Matrix B was partitioned into two separate matrices, one for operational objectives and one for sortie generation.

In August and September 1994, JAST operators and technologists completed the revised Matrices C, D, and E, accounting for the separate operational and logistics tracks. The final "QFD Flowdown" is illustrated in Figure 21.

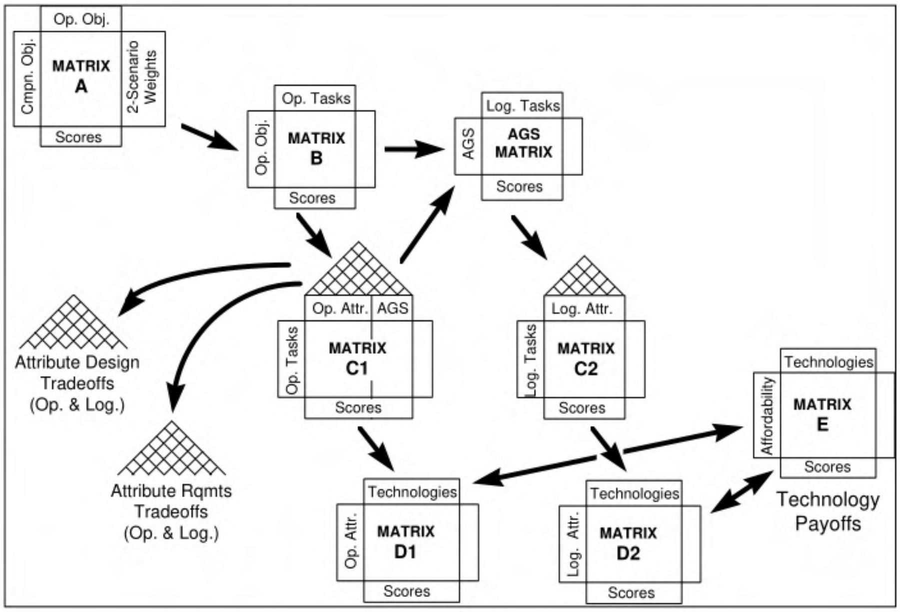

Figure 21: QFD Flowdown Matrices

In addition to the requirements "flowdown," the QFD exercise provided a starting point for tradeoffs among different qualities at the same level, through a "correlation roof" on the QFD matrices. The roof provides a means to assess the impact of every "how" across the top of the matrix, on every other "how." Two versions of the correlation roof were used on Matrix C, one for requirements trades and one for design trades. Corresponding "study questions" resulted from the correlation roof:

- For requirements trades, "Does improving or incorporating Attribute A affect the required level of Attribute B, or vice versa?" (example: reducing the signature will reduce the amount/sophistication of countermeasures required, for a given level of survivability).
- For design trades, "Does increasing or incorporating Attribute A affect (enhance or detract from) the **ability to incorporate** Attribute B?" (example: combat radius vs. payload typically must be traded off against each other).

The QFD analysis provided qualitative insight, and highlighted important areas for quantitative tradeoff studies. These trades have since begun, and will continue to be performed by service warfighters and government and industry technologists, throughout the requirements evolution process.

Table 4: Summary of QFD "Whats," "Hows," and Study Questions

Matrix	"What"	"How"	Study Question
A	Campaign Objectives	Operational Objectives	To what extent does operational objective X make a direct contribution to achievement of campaign objective Y?
"Operational" Linkages:			
B	Operational Objectives	Operational Tasks	To what extent does operational task X make a direct contribution to the achievement of operational objective Y?
C1	Operational Tasks	Attributes —including Ability to Generate Sorties	To what extent does attribute X make a direct contribution to the performance of operational task Y? And—To what extent does the Ability to Generate Sorties make a direct contribution to performance of operational task Y?
D1	Attributes	Technologies	To what extent does advancement in technology area X make a direct contribution to an **improvement** in attribute Y? (over levels achievable with current technology)
Logistics Linkages:			
AGS (B2)	Ability to Generate Sorties	Logistics Tasks	To what extent does logistic task X make a direct contribution to the Ability to Generate Sorties?
C2	Logistics Tasks	Logistics Attributes	To what extent does logistics attribute X make a direct contribution to the performance of logistics task Y?
D2	Logistics Attributes	Technologies	To what extent does an **advancement** in technology area X make a direct contribution to an **improvement** in logistics attribute Y? (over levels achievable with current technology)
Affordability:			
E	Affordability - Cost to mature - LCC payoff	Technologies	1. What is cost to mature Technology Area X? 2. What is potential LCC payoff of (advancement in) Technology Area X?

The next FPT meeting, on 27-30 September 1994 at the Naval Air Warfare Center, Aircraft Division (NAWCAD), Patuxent River, Maryland, was JAST's first major campaign-level simulation, using the Thunder campaign model. The FPT was divided into three planning "cells." Each cell fought the same scenario independently of the others. Each cell acted as the Joint Force Air Component Commander (JFACC) and supporting staff, making decisions as to how the friendly, or "Blue," forces would be employed to accomplish the Joint Force Commander's (JFC's) overall objectives.

The campaign was divided into phases defined by the accomplishment of certain objectives, for example:

- Phase I: Stop the advancing movement of the Forward Line of Troops (FLOT)
- Phase II: Restore FLOT to its original position

At the end of each campaign phase, certain results (i.e., information that would be available to the JFACC in an actual conflict) were analyzed and decisions made regarding the proper employment of Blue forces during the coming phase.

At certain points, results from the three cells were also analyzed and compared with each other, allowing the best use of force to be identified. This best use of force became the baseline for subsequent simulation iterations. This process provided confidence that the final results represented the best possible use of available forces.

For the first campaign simulation, the DPG Southwest Asia 2010 scenario was used, with "legacy" forces (i.e., AV-8s, F-16s, F/A-18C/Ds, and other assets currently programmed for 2010). The threat

laydown was also based on the 2010 timeframe. This simulation provided a baseline for comparison with later simulations, which would include a JAST-derived strike fighter.

The first campaign simulation was not entirely successful, and it was decided not to use the quantitative results of this wargame in JAST requirements analysis. However, many qualitative observations were made and key warfighting deficiencies of legacy systems were identified. Furthermore, the FPT gained experience using the Thunder model, and important lessons were learned regarding the joint strike warfare M&S process. For example:

- More extensive preparation would be required—in particular, using current and validated threats and weapons databases.
- The FPT cells were too large to effectively "fight" the campaign. In future simulations, the core Operational Advisory Group (OAG) members would be the primary players. FPT members would contribute their expertise, but the OAG would serve as final decision authority and focal point for interaction with the modelers and analysts.

These and other lessons were incorporated into the subsequent JAST wargames.[17, 18]

In October 1994, the JAST System Threat Working Group (JSTWG) was established as the focal point for threat analysis and other intelligence-related matters. The JSTWG was set up as an IPT with a JPO lead (b)(6) [redacted] and representation from the Defense Intelligence Agency, the National Security Agency, the Central Intelligence Agency, the National Air Intelligence Center, the National Ground Intelligence Center, the Missile & Space Intelligence Center, the Office of Naval Intelligence, and the Air Force 497th Intelligence Group.[19]

3.2.6 Important Concept Exploration Phase Requirements Results

As a result of the efforts in 1994, the highest-priority campaign objectives were identified as follows.[20]

- Destroy enemy ground forces; deny enemy critical objectives
- Establish air superiority & suppress enemy air defenses
- Rapidly deploy to theater of operations
- Establish maritime superiority to ensure access to ports and sea lanes of communication
- Protect friendly forces & rear area from attack by air

The corresponding key measures of effectiveness (MOEs) were identified as:

- Time to halt advance; distance penetrated (by enemy ground forces)
- Time to gain air superiority; time to drawdown threat Integrated Air Defense Systems (IADS)
- Time to build up forces
- Time to destroy "Red" naval forces
- Number of friendly casualties

The QFD assessment identified the following top-12 weapon system attributes:

- Target Acquisition
- Sortie Generation
- Interoperability
- Carrier Suitability
- Basing Flexibility
- Low Radar Signature
- Accuracy

- Range
- Logistic Footprint
- Payload
- Situational Awareness
- Low IR Signature

Radar-guided surface to air missiles (SAMs) were found to be the driving threat. To conduct successful strike operations, radar SAMs must be negated, suppressed, or destroyed. Low observability (LO) would be essential to survivability, especially in the early phases of a conflict when the enemy still had significant air defense capability. Inter-operability was determined essential to rapid deployability and improved sortie generation rates. Improved target acquisition and weapons accuracy were found to be synergistic for reducing the number of sorties required by significantly increasing the sortie effectiveness.[21]

3.3 Technology Maturation

The JAST Technology Maturation (TM) Directorate sought to identify and mature high-payoff technologies to support low-risk, affordable strike weapons system development for EMD. The TM Directorate consisted of seven IPTs under the direction of Dr. Donald C. McErlean, SES, USN, the former Air Vehicle Department Head at NAWCAD, Warminster, Pennsylvania. His deputy was Col [redacted] USAF, a technologist with past experience in the NASP Program. The TM IPTs' areas of responsibility corresponded roughly, but not exactly, to the eight technology area sub-teams of the JAST S&T Transition Team. The evolution from the S&T Transition area sub-teams, to the initial JAST TM IPTs, is illustrated in Figure 22.

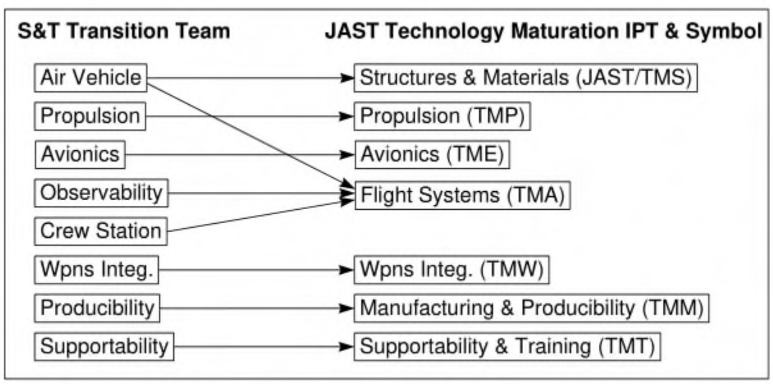

Figure 22: Initial JAST Technology Maturation IPTs

Each TM IPT was headed by a technology area expert assigned full-time to the JAST Program Office, with continuing support from the Air Force and Navy field sites. Consistent with the overall JAST philosophy, the IPTs were structured to facilitate *transition* of technologies already under development, to bring warfighters and technologists together, to provide balanced input from the services, and to develop a strong partnership with industry. An important and unique aspect of the whole JAST approach to technology maturation (Tech Mat) was the sharing of results among all of the JAST WSCs through Associate Contractor Agreements (ACAs), regardless of whether the work was performed by the government, by one or more of the WSCs, or by a specialized subcontractor or vendor. This sharing approach was taken to assure that maximum value was obtained from each Tech Mat investment.

To provide a balanced representation among the services, each IPT deputy typically represented the opposite service from the lead. Additional IPT members would include Air Force and Navy laboratory and acquisition personnel, industry technologists and engineers, experts from other government agencies and

from academia, along with representatives from the other JAST TM IPTs and Directorates as appropriate. In particular, continuous interaction with the JAST Requirements Directorate would be essential. The organization of a typical TM IPT is illustrated Figure 23.

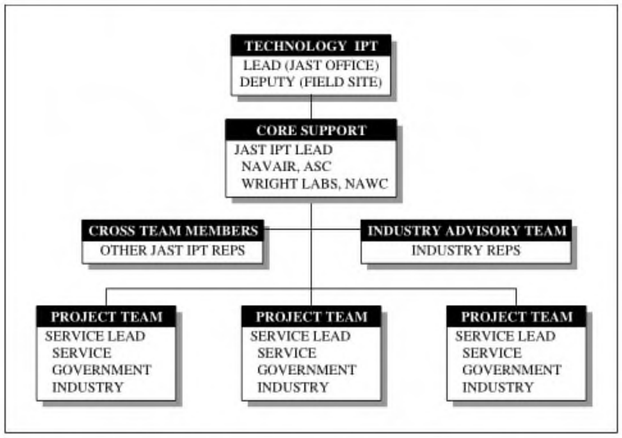

Figure 23: "Model" Technology Maturation IPT Organization

Supporting TM IPT members, including sub-team and project leads, remained assigned to their home organizations. The field offices—principally ASC, NAVAIR, Wright Laboratories, or the Naval Air Warfare Center (NAWC) sites—served as the executing agencies for most of the specific tasks and projects. For each project, IPT members assigned to the executing agency would provide day-to-day project management. (**Note**: This describes a "typical" IPT organization, but there was considerable variation in some cases to better suit each IPT's specific activities.)

The TM Directorate was staffed and organized very rapidly. [redacted] and Col [redacted] began to interview candidates for the IPT Lead positions immediately upon the formal establishment of the JAST Program on 27 January 1994, and had the positions filled by 5 February. In some cases, the Transition Team technology area leads became the permanent JAST IPT Leads. In other cases, IPT leads were recruited from other organizations. Deputies and additional government IPT members were also identified and assigned during January and early February 1994 (most of the initial field site personnel carried over from the S&T Transition Team). Industry members and specific sub-team leads and members were expected to be identified during the course of the JAST Concept Exploration phase, as specific projects evolved.

On 7-8 February 1994, the newly formed JAST TM Directorate met with the JAST S&T Transition Team at Wright-Patterson Air Force Base, to review suggested studies and projects, based on the Transition Team's findings to date. Preliminary investment plans and the database of 585 S&T projects developed by the Transition Team, along with project data sheets and technology roadmaps, were shared with the JAST TM Directorate.

The TM IPTs worked to refine the plan and develop specific Tech Mat programs and demonstrations in accordance with the JAST criteria of:

- Clear capability to reduce life cycle cost
- Commonality
  - Fully common solution ideal
  - Otherwise seek maximum cost commonality
- Maturity
  - Builds on existing S&T products (as opposed to all-new technology)
  - Able to meet low-risk EMD entry in 2000

To identify which technologies and projects would best meet these criteria, each IPT conducted more detailed "in-house" and contracted studies in several areas recommended by the JAST S&T Transition Team. Several government/industry conferences and forums were held to provide an opportunity for industry experts to discuss specific subjects. The chief purpose was to identify areas where high costs could be lowered through the application of improved technology or processes.

Another "filter" was a review of JAST technologies by the Office of the Director of Defense Research & Engineering (ODDR&E) headed by [redacted] in early 1994. This review was requested by Brig Gen Muellner, shortly after his selection as Program Director, to verify that all relevant S&T areas were being addressed, and to build confidence in the program's technology strategy through independent review.

Based on the results from all of these activities, each IPT identified key project areas and developed Tech Mat plans and programs for the next four to five years. A number of existing S&T programs and technology demonstrations were also identified in certain areas, where modest near-term JAST investments could yield early results and data (i.e., "low-hanging fruit"). These opportunities led to several technology demonstrations during FY95-96. The principal activities and high-payoff technology areas identified by each IPT are discussed below:

3.3.1 Structures & Materials (IPT Lead: Mr. Jim Browning)

A two-day Materials & Processes Workshop of JAST weapon system prime contractors and Air Force and Navy laboratory and acquisition personnel was held in May 1994 at Wright Laboratories. The Structures & Materials IPT also conducted a joint-service study on modular airframe design considerations, manufacturing processes, and costs.

High-Payoff Technology Areas Identified:

- Design for composites from the start (as opposed to part-for-part replacement of metal components, which has historically resulted in very limited and conservative use of composite materials in new aircraft)
  - Unitized composites
  - Materials characterization, design process integration
- High-temperature composites (for aft fuselage / engine interface structure)
- Inlet ducts / edges / front frames (LO-sensitive structural items)
- Structurally integrated sensor apertures
- Commonality / modularity
- Common airframe *production line*

3.3.2 Flight Systems (Lt Col [redacted])

The Flight Systems IPT sponsored assessments of subsystems technology (the Vehicle Integration Technology Planning Studies (VITPS)) and of flight mechanics (the Joint Service Advanced Flight Control Technology Studies (JSAFCTS)). Follow-on demonstration programs were planned in each area. In July 1994, the integration of helmet-mounted display technologies was identified as a near-term demonstration opportunity. This led to the Integrated Helmet Audio-Visual System (IHAVS) flight demonstration in FY95-96.

High-Payoff Technology Areas Identified:

- Tailless configurations (no vertical tail) with multi-axis thrust vectoring; quasi-tailless flight demonstration opportunity identified, using existing X-31 thrust vectoring test aircraft
- Integrated subsystems (utility power, thermal management) and the More Electric Aircraft (MEA) Program

- Advanced Vehicle Management Systems (VMS) technologies

3.3.3 Manufacturing & Producibility (b)(6) [redacted]

The Manufacturing & Producibility IPT met with Air Force and Navy manufacturing technology (ManTech) representatives during the spring of 1994 to identify manufacturing and producibility initiatives beneficial to JAST. The Lean Aircraft Initiative, for converting the U.S. aerospace industry into a "lean enterprise," was identified as an important opportunity for JAST investment and participation, and was started in September 1993 by Wright Laboratories, in conjunction with the Massachusetts Institute of Technology and members of the aircraft industry. The first major Lean Forum Conference with industry was held in August 1994, and representatives from 24 major defense contractors attended.

High-Payoff Technology Areas Identified:

- Lean Manufacturing
- Cellular manufacturing
- Advanced / flexible tooling
- Virtual manufacturing (i.e., simulate the manufacturing process, to provide data in support of design and management decision making)
- Integrated cost-design data base—enables design-to-cost

3.3.4 Propulsion (CDR (b)(6) [redacted]

The JAST propulsion technology demonstration program originally was planned to be centered around a new Generation 6 core* that would support two future engines: (1) one in the 23,000 to 28,000 lb. thrust class for a twin engine Navy aircraft; and (2) one of an undefined size for an Air Force F-16 replacement aircraft (most likely a single engine aircraft). To support this range of possible production engines, a ground demonstrator engine in the 25,000-lb. thrust class would be tested in 1997. The goal would be to demonstrate the optimum combination of weight reduction, fuel efficiency, performance, operability, supportability, and radar and infrared signature reduction at an affordable price. All of this was to be accomplished by incorporating advanced technologies developed under the Integrated High Performance Turbine Engine Technology (IHPTET) Program and other advanced technology programs.

A 9-month Engine Model Derivative Program (EMDP) study was begun in July 1994, to define the class of engine, and applicable technologies, for the FY97 JAST ground engine demonstration. For the preliminary phase, which concentrated on identifying leveraging technologies, three EMDP efforts were funded:

- General Electric: $1.35 million
- Pratt & Whitney: $1.33 million
- Allison: $0.84 million

The initial funding profile for the total JAST propulsion program was developed around building two ground demonstrator engines (plus spare hardware) and running 300 hours of ground tests (200 hours at sea level and 100 hours at altitude). The target funding was set at $250 million in the first 3 years, but eventually increased to $350 million. The tasks to be completed in the last two years of the JAST planning cycle (i.e., 1998-99, following the ground demonstrator engine tests) were left to be determined, with possible options including prototype flight engines or additional pre-EMD ground risk reduction. It was realized that additional funding would be necessary if it was decided to perform flight demonstrations with

* "Generation 6" refers to the next generation of fighter engines beyond the F119/F120 Advanced Tactical Fighter engine designs. Generation 3 refers to the F100 and its contemporaries; Gen 4 to the F119/F120; Gen 5 to F119/F120 advanced derivatives; and Gen 6 to the next generation new engines. A Gen 6 engine is a specific goal of the IHPTET Program.

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new engines. JAST flying demonstrator aircraft were anticipated, and funding was budgeted in the spring of 1994, but they were initially expected to use existing engines. These engines would be Contractor Furnished Equipment (CFE), with engine selection and integration to be performed by the prime weapon system contractors (WSCs). The propulsion Tech Mat funding profile therefore did not include engine development for JAST demonstrator aircraft.

During the JAST Concept Exploration studies (described in Section 3.4), the WSC's Preferred Weapons System Concept (PWSC) designs focused on General Electric (GE) F414 derivatives for a twin engine aircraft and Pratt & Whitney (P&W) F119 derivatives for a single engine aircraft. A twin-engine aircraft was primarily of interest to the U.S. Navy, while the Air Force and Marine Corps preferred single-engine. In fact, single-engine was considered to be the only technically feasible option for a short take off, vertical landing (STOVL) Marine Corps aircraft.

As the studies progressed, it became increasingly clear that propulsion decisions would be driven by affordability. This made a tri-service family of aircraft, all using the same, single engine, the preferred solution. The only engines determined suitable for a single-engine aircraft family, and available for low-risk EMD entry in 2000, were derivatives of the GE YF120 or the P&W F119 (both in the 35,000 LB thrust class).

The Navy has historically favored twin-engine aircraft for safety reasons. For the Navy to accept a single-engine aircraft as its next generation strike fighter, superior engine reliability equivalent to present twin engine reliability would have to be demonstrated. The focus of JAST propulsion Tech Mat therefore shifted from the development of a new mid-size engine, to the pursuit of increased reliability in a large-size derivative engine (see also Section 3.4.2).

High-Payoff Technology Areas Identified:

- Engine reliability for tri-service commonality (i.e., single-engine Navy aircraft)
  - More durable components
  - Advanced engine diagnostics/prognostics

In addition, it became increasingly apparent that derivative, rather than off-the-shelf, engines would be necessary for the JAST demonstrator aircraft in the CDP. The impacts of this development are discussed further in the following chapter.

3.3.5 Avionics (CDR (b)(6) [redacted] / Lt Col (b)(6) [redacted])

The first question facing the Avionics IPT was whether or not new technologies would be required. The answer lay in the challenge of meeting tri-service needs with avionics that supported commonality, single-seat functionality, and situational awareness for strike warfare effectiveness. The goals of each service drove the solution in a different manner: USN's survivable, first-day-of-the-war emphasis drove performance; USAF's desire for an F-16 replacement drove cost; and USMC's STOVL requirement drove weight. An avionics suite based on current-generation technologies could meet the likely JAST mission requirements at a cost of $12 to 18 million and a weight of 1,400 to 2,000 lb. Weapons system contractor allocations, however, allowed for an avionics suite costing $7 to 10 million and weighing 1,000 to 1,500 lb. Clearly, inserting maturing technologies to reach these weight and cost goals would be necessary. The Avionics IPT sought to enable affordable, common avionics by standardizing on an open systems architecture, validating a virtual systems engineering process, and conducting integrated technology demonstrations.[22]

The goal of establishing an open systems architecture was to reduce the cost of avionics and the impact of upgrades. By capitalizing on previous DoD investments in the F-22 integrated avionics, using appropriate commercial off-the-shelf (COTS) products and processes, and inserting selected technologies, reaching this goal was made easier. With the assistance of the WSCs, industry and government experts, the Avionics IPT

developed and released the Avionics Architecture Definition Document, Version 1.0, in August 1994. However, while this document was simply intended to communicate the JAST avionics architecture "vision" to industry, the general response was that it was too restrictive and too much like a specification. The Avionics IPT subsequently stated that Version 1.0 was not to be regarded as a binding specification. A more generic Version 2.0 of the architecture definition document was completed in September 1997 and Version 3.0 was released in December 1998 (and described in Section 5.5.2).[23]

"Virtual systems engineering" creates simulated building blocks of conceptual avionics systems functioning within an overall weapons system simulation—either constructive or real time, pilot in the loop—to assess the contributions of maturing technologies to total strike warfare effectiveness, and to perform substantive cost/benefit tradeoffs. The ultimate vision is to achieve a full "plug and play" capability within a real-time, piloted, mission-level simulation. Complementary non-real-time, constructive resource utilization simulations ensure that the chosen software algorithms and hardware components have sufficient capacity to perform the required functions throughout the mission profile. Such virtual, rapid prototyping activities provide an early in-depth understanding of avionics system requirements, leveraging technologies, and integration issues, ultimately reducing associated risks and costs. While some preliminary work in this area was accomplished during Concept Exploration (initially referred to as Avionics Technology Integration and Prototyping (ATIP)), the substantive effort began in the Concept Definition and Design Research phase Avionics Virtual Systems Engineering Prototype (AVSEP) contracts, and has continued (fully owned by the WSCs) in the CDP.[24, 25]

Selecting entrants for integrated technology demonstrations involved an extensive "necking down" process, because 383 of the original 585 technologies in the S&T Transition Team's database were avionics-related. Several "filters" were used: government and industry IPT members' inputs, QFD results, affordability findings, compatibility with the architecture definition, S&T funding, an independent "Sensor Gray Panel" review, and, especially, the WSCs' roadmaps. Eventually, these filters pointed to the following technologies: core processing, integrated radio frequency (RF) electronics, multifunction nose aperture (MFA), integrated electro-optical/infra-red sensor, on/off-board data fusion, and software reuse/schedule.

The objectives, plans and interrelationships of these three thrusts—open systems architecture, virtual systems engineering, and the integrated technology demonstrations—were captured in the JAST Avionics Concept Definition and Demonstration (JACDD) Plan, released in September 1994. This roadmap guided many of the subsequent decisions of the Avionics IPT, including the formulation of the specific demonstration programs discussed in the following chapters.

In addition to this groundwork laid by the Avionics IPT, three of the JAST BAA 94-1 efforts were avionics studies, i.e., Affordable Off-Board Architecture (McDonnell Douglas), Sensor Integration Trades and Architecture (Litton Amecom), and Affordable Next-Generation Avionics (Honeywell).

At the beginning of the JAST Program, there was some belief that future strike aircraft could rely, totally or in part, on off-board information sources. On-board avionics capabilities could then be dramatically reduced, yielding large cost savings. However, the BAA 94-1 studies found serious limitations to this concept:

- Strike operations would be excessively dependent on the availability of supporting assets for collecting and distributing information.
- Assuming availability of supporting assets, off-board information is primarily confined to the long-range, "situational awareness" zone. At closer ranges, off-board information suffers from
  - Time delays
  - Inadequate coverage and resolution in the immediate engagement area

On board sensors are therefore necessary to provide "hard" real-time information in the immediate vicinity of the strike weapon system. Off-board assets could be leveraged, when available, for improved situational

awareness and some types of targeting information. This potential makes on-board/off-board data fusion a desirable area for Tech Mat.

High-Payoff Technology Areas Identified:

- Core processing (including open systems architecture)
- Integrated RF systems (electronics and multifunction aperture)
- Integrated EO/IR systems
- On/off-board data fusion
- Software reuse/schedule

3.3.6 Weapons Integration (LCDR [redacted] & Maj [redacted])

The first Stores Certification meeting was held on 29 March 1994. This was followed by a Stores Certification Assessment and Study to identify cost drivers and make recommendations for cost reduction in the weapons certification process.

The Weapons Integration IPT also managed two of the BAA 94-1 studies on affordable weapons carriage (by McDonnell Douglas and Hughes). These studies were focused on identifying and evaluating alternatives to fully internal weapons carriage. All low observable aircraft, in service or under development, rely on fully internal stores carriage to preserve low signatures. On these aircraft, weapons bay size is a major driver of total airframe size and weight and thus cost. If low signatures could be achieved with external or conformal weapons carriage, then the airframe size/weight might be reduced and significant LCC savings achieved. However, the BAA 94-1 studies found that external carriage of stores does not support reduced signature needs for "first day" survivability. This shifted the emphasis towards minimizing the required size of the internal weapons bay through the use of smaller, precision weapons and the most efficient use of weapons bay volume.

High-Payoff Technology Areas Identified:

- Smaller bay size, for equivalent lethality, may be enabled by
  - Greater precision
  - Improved lethality munitions (e.g., improved 1,000-lb. penetrator); J-1000 near-term demonstration opportunity was identified
  - Improved packaging: for example, the 2,000-lb. Joint Direct Attack Munition (JDAM) is more compact than existing 2,000-lb. precision guided munitions such as the GBU-24/27, and therefore enables a smaller internal weapons bay.
- Improved stores certification process

3.3.7 Supportability & Training ([redacted])

The Supportability and Training IPT reviewed existing weapon system programs to focus investments on technology that would improve the affordability and supportability of future strike systems. The IPT identified two major deficiencies: 1) supporting the stealth systems was the largest man-hour driver associated with current stealth aircraft platforms; and 2) diagnostics performance of exiting aircraft platforms was lacking, causing many unnecessary maintenance actions. These two findings initiated efforts to research technologies that could improve these areas.

The IPT sponsored studies in supportable LO, commonality, diagnostics, and training. The IPT formed a supportable LO team to identify specific LO maintenance issues and to define a technology road map for the JAST Program. In 1994, a six-month contract was awarded to Technology Applications, Inc. (TAI) – through existing work at ASC – to perform a support and training commonality study to evaluate service differences and the affordability improvements of implementing a common support concept. As part of

BAA 94-2, the ASID contract was awarded to TRW, Inc. to initiate the research into diagnostics technology applicable to JAST. In addition, the IPT initiated four training efforts: an embedded training study, an evaluation of advanced visual technologies, demonstration of haptic technology (which translates physical sensation from virtual reality) as applied to maintenance training, and an evaluation of intelligent tutoring technology.

The Supportable Low Observables (SLO) IPT was formed in the earliest days of JAST to solve a major technology challenge for low observables: making stealth maintainable. The SLO team was formed by [redacted] and consisted of individuals with broad knowledge of signature technology, and interest in supportability, maintainability and affordability: [redacted] NAWCAD/Pax; [redacted] NAWCAD/Lakehurst; and [redacted] Wright Labs, WPAFB. The SLO Team spent much of 1994 reviewing contractor proposals for SLO, IRAD efforts, aircraft system "Lessons Learned", and preparing a SLO report and plan for future funded activities. Throughout 1994, the team had felt a need to break the paradigm of solving stealth challenges by adding special materials and processes; the "added materials" approach had worked well to control signature but had the unintended consequence of adding a significant logistic tail of manpower and materials to buy, store, install, remove, transport, refrigerate, and guard. The team's feelings were captured by [redacted] in a "SLO Mantra" that was intended as a challenge to the JAST contractors to reduce the stealth burden. The "Mantra" stated that a SLO vehicle was: "RAM-less, Tape-less, Butter-less, Paint-less, Chevron-less, Diverter-less, Bleed-less, Bypass-less, Tail-less, and Pitot-less."

None of these items were being developed before 1994 for purposes of improving stealth and maintainability. The topics dealt with special materials issues that are used to successfully reduce signature but, historically, are the top problem areas for maintainability and deployment challenges. The "Chevron-less" topic addresses an attempt to reduce the number of sawtooth shaping of the door and panel edges of stealth vehicles; sawtoothing inevitably leads to aircraft size, weight, and cost increases. The "Diverter-less, Bleed-less, and Bypass-less" items address improvements to the supersonic engine inlet system resulting in simplifications of actuated doors, bleed-plates, computers, and special treatments; simplification can result in lower weight and fewer items to stock, repair, etc. The "Tail-less" item suggested the desire to develop better control systems to allow the elimination of a heavy tail component. The "Pitot-less" item addressed a desire to develop a system that reduced the complexity – but increased the reliability of air data systems – while enhancing the stealth properties.

Much of the value in the Mantra was to provide an additional dimension to the design-space, while holding or improving stealth performance. The Mantra provided an "enabling SLO vector" for the JAST Program and made an impact on the Supportability & Training IPT. A majority of these Mantra items have found their way into the list of "baseline technologies" and have been demonstrated in the Concept Definition and Concept Demonstration Phases. Supportable LO is one of the leading contributors to improving the affordability and supportability of the JSF systems.

High-Payoff Technology Areas Identified:

- Advanced diagnostics
  - Sensors
  - Diagnostics architecture
- Supportable Low Observables
  - Material durability
  - Battle damage assessment and repair
  - RCS verification (especially in the shipboard environment)
- Common support systems / logistics process models
- Training & Mission Planning

3.3.8 Technology Maturation C/E Phase Summary

The technology studies sponsored by each IPT, together with the JAST QFD results and along with technology needs identified in the BAAs' 94-1 studies, provided a robust technology investment strategy. The technology strategy, and the program as a whole, was further reinforced by a Defense Science Board (DSB) review of the JAST program. The DSB Task Force on JAST met several times from April through September 1994. Their report, released in September 1994, noted that:

- "The list of technologies recommended for exploitation [by the Defense Science Board Task Force] has strong agreement with the priority list identified by the JAST Program."
- "There must be no confusion about the JAST role in maturing technologies to obtain affordable solutions to the services' requirements. Direction must reaffirm that the JAST role is **exploitation** of Science and Technology (S&T) programs and not broad technology development. JAST should be a **customer** for S&T programs technologies, not the manager or funding source for the spectrum of strike-related S&T programs."
- "The Task Force found that the numbers of new aircraft needed to sustain force levels in all three services require that there be revolutionary improvements in aircraft affordability…. An affordable fly-away cost range should be established as a goal."
- "The services should consider subordinating the marginal safety issues of one vs. two engines to affordability and commonality. JAST should quickly sort out the relative merits of incremental improvements from the two person crew and the added affordability of a single cockpit design. JAST should also quickly sort out the need for internal vs. external carriage of weapons against the range of scenarios, threats, and targets addressed."

The report strongly concurred with the JAST charter and mission, and reaffirmed that the JAST Program was going in the right direction and looking at the right issues.[26]

3.4 Weapon System Concept Exploration

3.4.1 Prime Contractor Concept Exploration (CE) Studies

The CE studies were relatively unconstrained and each contractor was free to define his own procedure. However, the efforts by the four prime WSCs—Boeing, Lockheed, McDonnell Douglas, and Northrop Grumman—had many points in common. All adopted an overall approach, which included the following elements:

- Identify candidate technologies, concepts, and processes
- Perform initial screening, and integrate logical sets of these candidates into future strike weapon system concept designs
- Evaluate these advanced weapon systems concepts against some baseline, in order to assess the costs, risks, and benefits of each set of candidate technologies/concepts/processes
- Prioritize the candidate technologies/concepts/processes according to their system-level benefits, considering capability enhancements, but giving primary emphasis to *affordability*
- Develop preliminary risk reduction / Tech Mat plans, for the highest-ranked candidates

All used some variation of the QFD process in performing their prioritization.

The extent to which the WSCs included their Advanced Short Takeoff/Vertical Landing (ASTOVL) work in the JAST studies varied from contractor to contractor. The purpose of the CE studies was not to assess or develop specific aircraft designs, but rather to identify high-leverage areas for JAST investment during the period prior to any specific development decision(s). As such, aircraft designs were not the central focus of the BAA 94-1 studies, but rather a tool for the purpose of evaluating candidate technologies. Some of the contractors presented an array of design options, including designs derived from the A/F-X,

MRF, and/or various other stealth aircraft programs. Others concentrated specifically and exclusively on concepts derived from their ASTOVL designs.

The WSCs enthusiastically embraced the idea of giving primary emphasis to affordability. Major contributors to affordability, in general order of importance, were found to be:

- Commonality/Modularity
- Selected advanced technologies
- Affordable requirements, including appropriate compromises for commonality
- Improved business practices

Specific high-payoff technology and requirements items are listed separately below.

High-Payoff Technologies: Most WSCs agreed that investments in the following areas could yield large reductions in LCC (not listed in order of importance):

- Advanced/Integrated Diagnostics
- Low Observables Supportability
- Open Systems Avionics Architecture
- Integrated Sensors/Apertures
- More Electric Airframe and Integrated Subsystems
- Unitized Composite Structures
- Weapons integration options for reduced internal weapons bay size
- Lean Manufacturing initiatives; "virtual" manufacturing; agile/flexible tooling

Some of these were expected to yield LCC savings directly, while others contributed to affordability by enabling a highly common family of aircraft to satisfy all services' requirements.

High-Leverage Requirements Trades: There was also a consensus that requirements decisions in the following four areas would have a strong effect on cost:

- Extent of on-board avionics capability
- Weapons carriage (internal/external/conformal; bay size if internal)
- 1 vs. 2 engines
- 1 vs. 2 crew

Some of the BAA 94-1 studies already underway were looking into the first two areas (findings were discussed in Sections 3.3.5 and 3.3.6). Studies of the remaining two issues were subsequently initiated as described in the following section.

All of the WSCs converged on a "tri-service family" of aircraft with common engine turbomachinery, a common single-seat cockpit, common avionics, and a high degree of commonality throughout most of the airframe, as the most affordable overall weapon system solution. As this became apparent, they concentrated on assessing the technical feasibility of such a family. The WSCs concluded that it was feasible, and they identified potential sources for unit flyaway and LCC savings.

All of the WSCs evaluated a twin-engine U.S. Navy option at some point in their studies. However, this would have required either a separate aircraft design for the Navy, or significant design variation within the "family," i.e., a completely unique fuselage to accommodate two engines. All agreed that a significant affordability benefit would result if a single-engine Navy solution could be accepted. Furthermore, despite a strong Navy warfighter interest in carrying current-generation, 2,000 lb class munitions internally, WSC affordability studies showed that it was strongly desirable *not* to do so. The final decision, however, was deferred until a more detailed analysis of requirements and of the technical feasibility of potential alternatives (which is discussed in Section 4.3.1) could be made.

3.4.2 Additional Studies: 1 vs. 2 Engines and 1 vs. 2 Aircrew

As noted above, the CE studies pointed to the desirability of a single-engine, single-seat solution for all services. However, in both areas, the Navy has historically favored the opposite. The Navy's predecessor to JAST, the A/F-X, would have been a twin-engine, two-seat aircraft. However, the objective of JAST was not to just continue what each service was doing before the Bottom-Up Review, but rather to find a more affordable collective solution. Brig Gen Muellner and RADM Steidle discussed the options extensively with the Director of Naval Aviation Requirements (N-88), Naval Requirements (N-8), and the Chief of Naval Operations (CNO).

The JAST position was to deliver to the U.S. Navy whatever the Navy required—but the Navy would have to pay for it if it was different from what the other two services needed. The Marine Corps was already committed to a single-engine aircraft, because a twin-engine STOVL fighter that meets the services' single-engine failure safety criteria is simply not feasible with available technology. The Air Force's highest priority was affordability, and their requirements could easily be met with a CTOL version of the Marine Corps aircraft. That would leave the Navy as the only customer—and therefore responsible for the full cost—of a twin-engine concept. Muellner and Steidle asked what it would take to make a single engine solution acceptable to the Navy. The answer was that it would take a commitment to work towards improved engine reliability, so that a single-engine aircraft could achieve current twin-engine safety levels, i.e., comparable to an F-18C.[27, 28]

In the summer of 1994, two independent research institutes—Johns Hopkins University/Applied Physics Laboratory (JHU/APL), and Georgia Tech Research Institute (GTRI)—were asked to study the issue of 1 vs. 2 engines. The reason for having these studies performed by research institutes, rather than by the WSCs, was to avoid any reluctance to present specific results that might jeopardize WSC competitive positions. The most objective assessment could be expected from sources that did not stand to gain or lose by the study results. Study plans were presented to the program office in August, and contracts of approximately $230,000 each were awarded on 1 September 1994. Both institutions reviewed existing databases to identify information that was relevant to the JAST goals of affordability, supportability, survivability and safety. Preliminary results, presented on 3 October 1994, indicated a significant LCC advantage—7% to 12%—for single-engine aircraft, in spite of higher peacetime attrition rates. The studies also found that having two engines did not significantly reduce combat losses, relative to single-engine fighters. Final reports for the studies were delivered in early 1995. A follow-on study was then initiated in order to identify specific technologies that could help to achieve present F-18C safety levels with a single engine (Section 4.4.3).[29]

A study of 1 vs. 2 crew was begun slightly later, in February 1995. Veda, Inc. was awarded the contract for this study. The results were similar to the 1 vs. 2 engine studies: if all JAST variants could be single-seat, then LCC savings of 6% to 8% were expected for the affected variants. This would be acceptable to the Navy as long as space was provided in the aircraft, and engineering work performed up-front, to support a 2-seat version if later deemed necessary.[30]

With these two key decisions made, JAST invested in Tech Mat and related activities to mitigate the associated risks. Propulsion efforts became heavily oriented towards improved reliability and advanced diagnostics/prognostics, while single-crew operation has become a major focus of cockpit technology (e.g. the IHAVS flight demonstration described in Section 4.3.1), avionics definition, and mission-level pilot-in-the-loop simulation activities.

3.4.3 Convergence on a "Tri-Service Family"

While the JAST Program initially aimed at developing common technologies and components, a high level of airframe commonality was not initially assumed or dictated. Moreover, the diverse requirements

of the three services seemed to point away from airframe commonality. The options for meeting these diverse needs included:

A. 3 separate aircraft: USMC, USAF, and USN. 3 development programs

B. 2 families of aircraft: USMC/USAF and USN/USAF. 2 development programs

C. 1 family (USMC/USAF) and a USN-unique aircraft. 2 development programs

D. 1 family of aircraft: USMC/USAF/USN. 1 development program

These options are summarized in Figure 24.

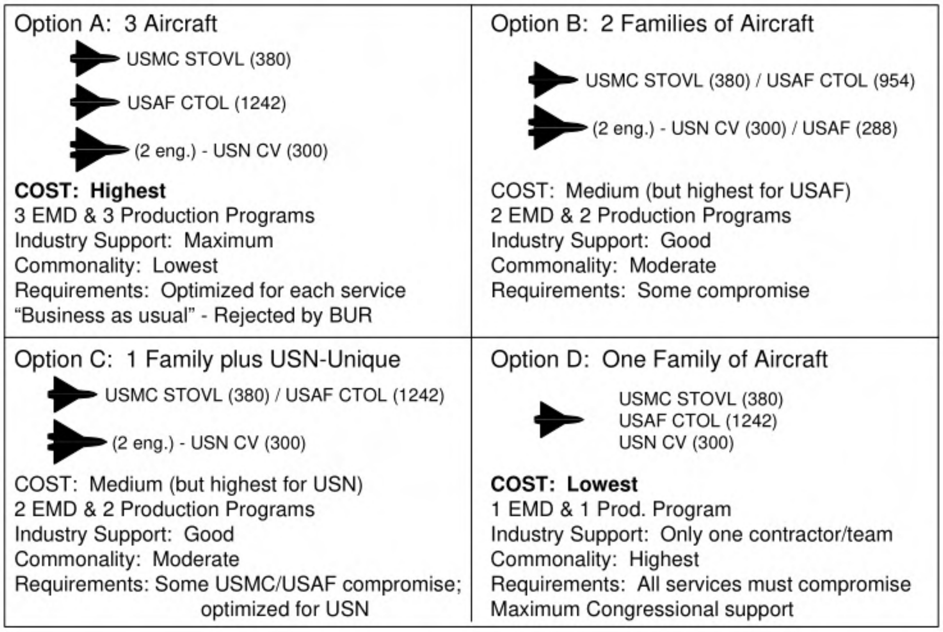

Figure 24: Program Strategy Alternatives

Analysis by the JPO, together with the emerging results from the WSCs, strongly supported Option D, a single family of aircraft. Even with the benefit achieved through the use of common technologies and components, 2 or 3 separate development and production programs did not appear to be affordable. The JAST Program therefore completed the CE phase with the clear goal of developing requirements and technologies that would support development of a single, tri-service family of strike aircraft. Commonality was estimated to be the single largest contributor to affordability—18% to 25% LCC savings, relative to three aircraft developed and produced separately. A common production line was also envisioned, with service-unique components introduced during assembly to produce the three variants. This common production line concept is displayed in Figure 25.

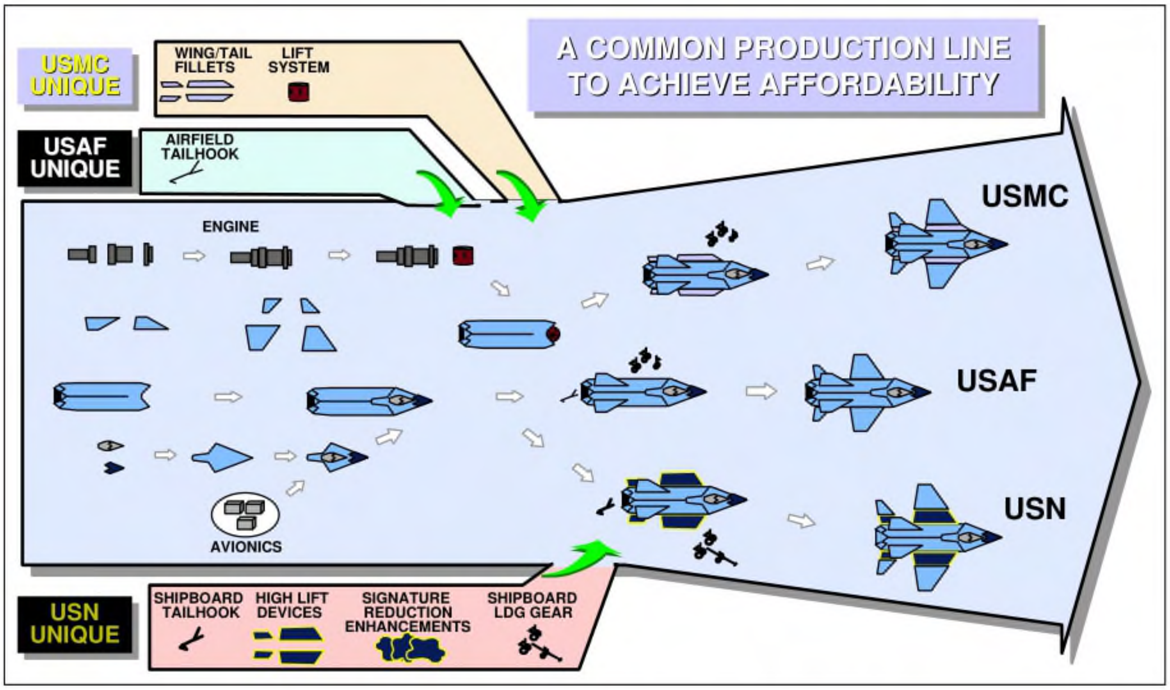

Figure 25: Common Production Line Concept

3.5 Transition to Concept Definition & Design Research

3.5.1 Broad Agency Announcement (BAA) 94-2

Planning for the second major JAST solicitation—which would initiate the next phase, Concept Development—began in mid-June, 1994. The first draft of BAA 94-2 was prepared by late June, and staffing and revision was accomplished during July. A second JAST Industry Day was held on 28 July. A short announcement in the *Commerce Business Daily* (*CBD*) served as an invitation to the second Industry Day, at which time a draft BAA 94-2 Information Package on diskette was provided to attendees, for review and comment. Comments were due by 14 August. BAA 94-2 appeared in the CBD on 1 September. The BAA itself was very short, containing only a short description of objectives, plus instructions on how to obtain the computer disk with the detailed Information Package. BAA 94-2 applied streamlining lessons learned from BAA 94-1 with the goal of being completely paperless.

BAA 94-2 was more specific than BAA 94-1 in terms of the work that was being solicited. In addition to concept development by the airframe prime contractors, BAA 94-2 specifically sought to involve the major engine companies, and also solicited Tech Mat work in avionics, structures & materials, supportability (advanced diagnostics), and modeling & simulation. 150 proposals were received by the due date of 4 November. Evaluation was completed by 29 November, and 26 awards were made. This was the first-ever completely electronic procurement—from the solicitation through the contracts—by a DoD program. Some of the contracts represented partial awards for some but not all of the work contained in a given proposal. This was possible because of the flexibility allowed by BAAs. Also, efforts contained in multiple proposals by the same company were, in two cases, combined. As a result, 24 contracts with a total value of $131 million were awarded on 16 December 1994.

Lessons learned from the BAA 94-1 source selection were incorporated into the 94-2 process, and additional functions and capabilities were added. Most notably, the 94-2 contracts were awarded electronically, complete with electronic signatures. Commensurate with the more advanced phase of the

program and the higher value of the contracts to be awarded, the proposal evaluation process was considerably more intensive than it had been for BAA 94-1. Even so, the timescale for source selection and contract award—4 weeks and 2 weeks respectively—was just about twice as long as for BAA 94-1. Twice as many contracts were awarded, with a total value more than ten times as large. The end-to-end time from initial planning to contract award was still only 6 months. For the benefit of other acquisition programs as well as subsequent JAST procurements, a Lessons Learned document was written and made available upon completion of the 94-2 effort. (Further discussion of electronic source selection can be found in Section 8.2.2.)[31, 32]

3.5.2 Absorption of the DARPA/UK ASTOVL Program

During the JAST Concept Exploration phase, there was some interaction and cooperation between JAST and the DARPA ASTOVL Program Office. Certain government personnel from the two programs participated in each other's reviews with the contractors. Government-to-government dialogue served to insure: that the programs' efforts were complementary and not duplicative; that ASTOVL could leverage JAST technology work; and that the emerging ASTOVL concepts received consideration in JAST requirements development. Both programs' leadership agreed that if the ongoing ASTOVL Risk Reduction phase proved successful, *and showed the potential to satisfy emerging JAST requirements* (interpreted by Maj Gen Muellner to mean an ASTOVL aircraft, and its CTOL variant(s), satisfying the needs of at least two of the three services participating in JAST), then JAST would become a formal participant in the flight demonstration phase, beginning in FY96. JAST would then fund roughly one third of the flight demonstration phase of ASTOVL, DARPA would fund one third, and the UK would fund one third. However, in October 1994, Congress directed that the programs be combined immediately. The implications of this action are discussed in the following chapter.

3.6 Summary of Concept Exploration Phase

In its first year of existence, the JAST Program completed the first round of industry Concept Exploration studies and awarded follow-on Concept Definition & Design Research contracts. Preliminary requirements analysis was accomplished, including an initial Strategy-to-Task-to-Technology analysis, and the first in a series of campaign simulations. Detailed technology studies were performed, and high-payoff areas were identified for Tech Mat investment, with contribution to life cycle affordability as the primary selection criterion.

JAST pioneered many ways of "doing business differently." The fully joint Program Office, with no executive service, was working together to provide next-generation strike weapons systems for the U.S. Marine Corps, the U.S. Navy, and the U.S. Air Force. Warfighters and technologists together were accomplishing requirements analysis, with a focus on life cycle affordability. Technology Integrated Product Teams brought together laboratory and acquisition personnel from the Air Force and the Navy to work towards common technology solutions. Two major electronic source selection efforts were accomplished.

Most importantly, JAST studies indicated that significant cost savings could be achieved through commonality, the application of advanced technology for affordability, and most of all, through affordable requirements. This information supported the decision to focus on a single-engine, single-crew, tri-service family of strike aircraft. The services' acceptance of this direction for the program demonstrated their willingness to set aside traditional preferences in the interest of affordability.

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1 *JAST Acquisition Strategy*, Executive Summary, Joint Advanced Strike Technology Program Office, 20 July 1994.

2 Muellner, George K., Lt Gen USAF, former Principal Deputy to the Assistant Secretary of the Air Force (Acquisition), Interviewed by [redacted], 22 and 28 January 1998.

[3] [redacted] Interviewed by [redacted] 20 October 1997.
[4] *Ibid.*
[5] JAST Broad Agency Announcement (BAA) 94-1, *Commerce Business Daily*, 17 January 1994.
[6] [redacted] "The Joint Advanced Strike Technology (JAST) Program Streamlined Acquisition and Paperless Proposal Evaluation Process," *Program Manager*, September-October 1994, pp. 33-38.
[7] *Ibid.*
[8] [redacted] 1997.
[9] *Joint Advanced Strike Technology Program Broad Agency Announcement 94-1: Application of Paperless Evaluation and Streamlined Acquisition Processes*, JAST Program Office, 10 October 1994.
[10] *Joint Advanced Strike Technology Program Master Plan*, JAST Program Office, Arlington, Virginia, May 1994.
[11] *Charter for the Joint Advanced Strike Technology (JAST) Program*, approved by John M. Deutch, Deputy Secretary of Defense, 12 August 1994.
[12] *Ibid.*
[13] *Joint Advanced Strike Technology Program Master Plan*, JAST Program Office, Arlington, Virginia, May 1994.
[14] [redacted] Comments provided to the authors, 4 February 1999.
[15] *Ibid.*
[16] [redacted] USAF ASC/LU, Letter to [redacted] 1 May 1998.
[17] [redacted] former Task Leader for ANSER support to JAST Requirements Directorate, Interviewed by D. Aronstein, September 1997.
[18] *Joint Advanced Strike Technology Newsletter*, JAST Program Office, Issues 5, 6, and 7.
[19] [redacted] JSF Threat/C4I Division Lead, Interviewed by D. Aronstein, 26 February 1998.
[20] Muellner, George K., MGen USAF, JAST Program Manager, *Joint Advanced Strike Technology Program Heading Check*, Briefing, November 1994.
[21] *Ibid.*
[22] [redacted] Lt Col USAF, former JAST Avionics IPT Lead, Letter to [redacted] with attached comments, 12 April 1998.
[23] [redacted] CDR USN, former JSF Mission Systems IPT Lead, Interviewed by [redacted] 3 October 1997.
[24] [redacted] 1998.
[25] [redacted] Lt Col USAF, JAST Avionics IPT Lead, "Joint Advanced Strike Technology Program Avionics Overview," *1995 Avionics Conference and Exhibition*, ERA Technology Ltd., Heathrow, U.K., 29-30 Nov 1995.
[26] *Report of the Defense Science Board Task Force on Joint Advanced Strike Technology (JAST) Program*, Office of the Under Secretary of Defense for Acquisition & Technology, September 1994.
[27] Muellner, 1998.
[28] Steidle, Craig E., RADM USN, Deputy Commander of the Naval Air Systems Command, Interviewed by [redacted] 10 April 1998.
[29] [redacted] *Joint Strike Fighter (JSF) Program History and Propulsion System Development* (Draft), ANSER, Arlington, Virginia, 5 September 1997.
[30] Steidle, 1998.
[31] *JAST Program Acquisition Streamlining and Electronic Source Selection Process Demonstration*, Briefing, ANSER, 1995.
[32] [redacted] Maj USAF, *JAST BAA 94-2 Lessons Learned*, 19 December 1994.

4 Concept Definition & Design Research Phase (CDDR)

The Concept Definition & Design Research (CDDR) phase of the JAST/JSF Program proceeded from December 1994 through November 1996. The CDDR phase, also referred to as the Concept Development phase, formed the second half of what is normally Phase Zero, Concept Exploration & Definition (CE/D), of a formal DoD acquisition program.

The primary conclusion of the preceding Concept Exploration phase was that a highly common, tri-service family of strike aircraft was potentially feasible, and represented the most affordable solution to the participating services' next-generation strike warfare needs. Accordingly, the principal activities during CDDR were as follows:

- Efforts by the prime contractors to develop specific weapon system *designs* incorporating the tri-service family concept
- Initiation of primary and alternate engine preliminary design programs
- Defining and initiating the necessary leveraging demonstrations to bring individual technologies to low risk, with moderate integration risk, for EMD entry around the year 2000
- Continuing Requirements definition, including the release of the first Joint Initial Requirements Document (JIRD I). The original plan was to release a Joint Mission Need Statement (JMNS), but this evolved into the JIRD by the time it was completed
- Competitive downselect, accomplished from June through November 1996, to two prime contractor/teams for the subsequent Concept Demonstration phase

The JAST Program was renamed the JSF Program in early 1996 and is therefore referred to in the present chapter as JAST, JSF, or both, depending on the context and the timeframe being discussed. JSF was designated an Acquisition Category I, DoD (ACAT I D) acquisition program by the Under Secretary of Defense (Acquisition & Technology) (USD(A&T)) in May 1996. The CDDR phase culminated with the Milestone I decision and the award of CDP weapons system and propulsion contracts, in November 1996.

4.1 Program Management

4.1.1 Broad Agency Announcement (BAA) 94-2 Contracts

The CDDR phase began with the award of 24 contracts, worth a total of $128 million, under BAA 94-2. These included contracts to the prime WSCs, plus numerous Tech Mat projects and three projects related to requirements modeling, simulation & analysis. These contracts, awarded on 16 December 1994, are listed in Table 5.

Table 5: Contracts Awarded Under BAA 94-2

Weapon System Concept Definition & Design Research (subtotal $99.8 M)	Boeing Defense & Space	$27.614 M
	Lockheed	$19.900 M
	McDonnell Douglas/British Aerospace (MDA/BAe)	$28.194 M
	Northrop Grumman	$24.086 M
Note: Northrop Grumman Corporation teamed with MDA/BAe following contract award, and the two contracts were then managed as one through the CDDR Phase.		
Propulsion (subtotal $9.4 M)		
JAST Propulsion System Demos	Pratt & Whitney	$5.448 M
Low Cost Nozzles, Turbocooler Demo	General Electric (GE)	$3.657 M
Fluidic Thrust Vectoring Nozzle Study	Rockwell	$0.278 M
Avionics (subtotal $13.9 M)		
Avionics Virtual Systems Engineering Prototyping (AVSEP)	Boeing Defense & Space	$2.289 M
AVSEP	Northrop Grumman / Hughes / TRW / RTI	$2.215 M
AVSEP	Texas Instruments / Honeywell / Litton Amecom	$2.464 M
On-Board Off-Board Information Fusion	Lockheed—Fort Worth	$2.016 M
Structurally Integrated Reconfigurable Multifunction Apertures (SIRMA) Study	Lockheed—Fort Worth	$0.442 M
Wideband Integrated Forebody Tech Maturation	Hughes / Boeing	$1.310 M
Scaleable Multiprocessing System	Unisys / McDonnell Douglas	$1.210 M
Affordable RF/IF Packaging	Westinghouse	$0.315 M
Affordable Modular EO/IR Sensor Subsystem	Martin Marietta	$0.536 M
RF Technology Maturation	Rockwell Collins	$0.719 M
Secure Avionics Architecture Concept Development	Hughes / Trusted Info. Systems	$0.292 M
Compared Performance of Proposed Scaleable Coherent Interface / Real Time (SCI/RT) Mechanisms	D. Gustavson	$0.050 M
Structures & Materials		
JAST Multi-Service Common Airframe	Boeing / Dassault	$1.741 M
Supportability & Training		
Advanced Strike Integrated Diagnostics (ASID)	TRW	$2.004 M
Modeling, Simulation & Analysis (reserved for Small Businesses) (subtotal $1.1 M)		
Spreadsheet Methodology for Tradeoff Analysis	ASI	$0.347 M
Advanced Survivability Model for Strike Warfare	Aerodyne	$0.251 M
Off-Board MS&A Concept Def. & Design Research	Geodynamics	$0.487 M
TOTAL	**24 Contracts**	**$128 M**

4.1.2 ASTOVL Absorption and FY95 Funding Issues

Perhaps the greatest challenge faced by JAST at the beginning of CDDR phase, both financially and programmatically, was integrating the DARPA/UK Advanced Short Takeoff/Vertical Landing (ASTOVL) Program, ordered merged by Congressional direction in October 1994. The ASTOVL Program brought a lot of high quality, talented people into the JAST Office. It also brought the United Kingdom into the program, under a Memorandum of Understanding (MOU) signed in August 1994. The challenges lay in defining the roles and responsibilities within the new organization, and in aligning the activities of what

were previously two separate programs, into a single, coherent, consistent effort within existing budgets. The short-term problem was how to fund the combined JAST and ASTOVL program in FY95, with less funding than JAST had planned without the ASTOVL merger.

The initial JAST investment plan called for $201 million in FY95, and this was included in the FY95 President's Budget Request, submitted to Congress in February 1994. Congress, however, only appropriated $186 million. Undistributed reductions ("taxes") further reduced the FY95 JAST budget by $8 million. In addition, although JAST had absorbed the ASTOVL program, $38 million of FY95 ASTOVL funding was *not* transferred to JAST. Finally, other congressional cuts also affected many service-funded S&T programs, including $22 million from programs that were supportive of JAST. JAST therefore absorbed the most critical of these, including the More Electric Aircraft (MEA) Initiative, Subsystems Integration Technology (SUIT), and avionics technology initiatives, totaling $7 million. The FY95 JAST budget is summarized in Table 6.

Table 6: FY95 JAST Budget[1]

FY95 President's Budget Request (Feb 94)	**$201 M**
Congressional General Reduction	**-$15 M**
Appropriated	$186 M
"Taxes" (USN & USAF Undistributed Reductions)	**-$8 M**
Total Estimated Program Value	**$178 M**
Unfunded Scope Absorbed	
ASTOVL	-$38 M
Science & Technology (S&T) Programs (MEA, SUIT, Avionics)	-$7 M
(Unfunded S&T not absorbed: $15 M)	
FY95 Bottom Line	
(for previously planned JAST FY95 effort)	**$133 M**
Total Impact:	**-$68M (34%)**

The major near-term changes to accommodate the cuts were as follows:

- Reduce BAA 94-2 System Design/Development $21.4 million
- Cancel Propulsion Ground Engine Demo $12.7 million
- Cancel BAA 94-2 Weapons Integration efforts $8.0 million
- Other Technology Maturation cuts/reductions $21.2 million
- Reduce ASTOVL government technical support $1.7 million
- Requirements (strike demos & assessments) $3.8 million

These adjustments resolved the near-term funding situation. However, significant issues remained for the long term. DARPA/UK funding for ASTOVL would have to be restored if the program was to be executable beyond FY95.

The original JAST strategy was to select two advanced strike aircraft concepts in FY96, and award contracts to conduct flight demonstration of those concepts. While specific technology content was yet to be determined, the concept demonstrator aircraft (CDA) were envisioned as being relatively low-cost—possibly sub-scale—and making use of existing off-the-shelf engines. The demonstration of two competing *families* of aircraft, each including a STOVL variant, went somewhat beyond the original plan, and added considerable scope to the flight demonstration effort:

- Two tailored airframes would probably be required to demonstrate the essential characteristics of each proposed family of variants. This would make a total of four demonstrator aircraft, whereas the original plan could have involved as few as two.
- None of the ASTOVL designs used solely off-the-shelf engines. Boeing, Lockheed and (initially) McDonnell Douglas all required an F119 or YF120 derivative engine (i.e., using the high pressure core[*] with a much larger low pressure system), while Northrop Grumman's Lift + Lift/Cruise concept used a nearly off-the-shelf F119 but required a new lift engine (and this concept was ultimately retained after Northrop Grumman teamed with McDonnell Douglas).
- To convincingly demonstrate STOVL capability, the CDA would have to be full scale. Only the Lift + Lift/Cruise concept could be demonstrated at full scale with a stock F119 main engine, and, as noted above, this would still require the development of a lift engine.
- Finally, the competing concepts' propulsive lift systems were all different. Thus, the CDP would involve the development of not just one, but two different propulsion systems, each involving a new or derivative engine; whereas the original JAST plan was not to perform any propulsion system development for the CDA.

4.1.3 Concept Demonstration Alternatives

During 1995, three possible strategies were evaluated to fit the new demonstration effort into something resembling the original funding profile. The first involved a "Synergistic Demonstrator Engine" or "Common Demonstrator Engine" (SDE or CDE), whereby a single engine derivative would power the CDA of two competing contractors.

By this time, the McDonnell Douglas/Northrop Grumman/British Aerospace (MDA/NGC/BAe) team had announced their selection of the Lift + Lift/Cruise concept for STOVL propulsion. The pool of concepts was as follows:

- **Boeing: Direct lift**, using an F119 engine with a new low-pressure spool.
- **Lockheed: Shaft-driven lift fan**, using an F119 with a new low pressure spool and shaft power extraction through a clutch to a lift fan.
- **MDA/NGC/BAe: Lift + lift/cruise**, using a stock F119 with a new nozzle plus a new GE/Allison lift engine

While most of the design concepts changed considerably from the previous ASTOVL configurations, primarily to accommodate Navy carrier suitability requirements, all of the WSCs retained their ASTOVL propulsion/powered lift concepts. The SDE effort focused on finding a "midpoint" F119 derivative that could power both the Lockheed and Boeing demonstrator aircraft. It was acknowledged that an SDE would contribute very little toward EMD risk reduction for the engine, but might allow the program to stay within its budget and thereby allow risk reduction on the aircraft concepts.

After thorough analysis, the SDE was rejected for two main reasons. First, the Lockheed and Boeing propulsion systems had very different requirements, even though both were based on the same F119 core. Boeing simply needed as much static, dry thrust as possible. Lockheed, on the other hand, needed a less aggressive thrust increase, but extra shaft power for the lift fan. For these and other technical reasons, a single solution would not be adequate to demonstrate both concepts. Second, even if a Lockheed-Boeing SDE could be built, it would only address one of three possible combinations of competitors in the coming phase. If the MDA/NGC/BAe team advanced to CDP, it would be necessary to develop a lift engine for that team, plus an F119 derivative for either Lockheed or Boeing. The SDE/CDE idea was therefore rejected during the summer of 1995.[2]

[*] An engine core is comprised of the high pressure compressor, high pressure turbine and combustion sections. A full-up turbofan engine includes the low spool—the fan (low pressure compressor) and low pressure turbine—as well as the afterburner, nozzle and accessories.

The other plan involved making the downselect to a single contractor based on flight demonstration of CTOL variants only. Under this plan, a source selection would occur following initial flight demonstration of CTOL variants during FY99. CTOL flight demo results would be a factor in the source selection. The winner would then conduct STOVL flight demonstration in FY00, and EMD would begin in FY01. This plan was conceived to avoid the cost of developing two separate flightworthy STOVL propulsion systems. However, this plan also had serious shortcomings. First, STOVL capability was generally considered to be the highest risk aspect of the "family of aircraft" concept. If two competing concepts were to be demonstrated at all, then it made sense to demonstrate STOVL capability prior to making the final downselect. Second, the winning contractor would not be prepared to fly a STOVL demonstrator in FY00 without considerable prior investment in STOVL propulsion system development. Without knowing in advance who the winner would be, the program would have to fund the development of both contractors' powered lift systems. This option would therefore incur *most* of the cost of developing two STOVL propulsion systems, but stopping one of them just short of flight test would fail to accomplish the greatest part of the desired risk reduction.[3]

A final, and equally undesirable, option was to fund the flight demonstration of two competing tri-service concepts, including the necessary STOVL propulsion development, by taking the funding out of the JAST TM budget. This, however, would essentially strip away most of the foundation of the JAST Program.

4.1.4 Change of Command and Program Office Reorganization

In August 1995, Lt Gen (sel) Muellner received a new assignment in the Pentagon, as Principal Deputy to the Assistant Secretary of the Air Force for Acquisition. RADM Steidle took over as JAST Program Director. In accordance with JAST's joint-service management concept, the reporting chain switched from the Assistant Secretary of the Navy for Research, Development & Acquisition, [redacted] to the Assistant Secretary of the Air Force for Acquisition (SAF/AQ). Ms. Darlene Druyun was acting SAF/AQ at the time, as the previous incumbent, [redacted] had recently been killed in an Air Force aircraft crash during performance of his official duties. Later that year, Mr. Arthur Money was appointed as [redacted] successor.

During CDDR, several changes took place within the JAST Program Office, some related to the recent absorption of the ASTOVL program, and some for other reasons. The following ASTOVL personnel joined the JAST Program Office at the end of 1994: [redacted] (Program Manager); Col [redacted] USMC (Deputy Program Manager, Department of the Navy); CDR [redacted] RN (Deputy Program Manager, UK Royal Navy); [redacted] (Deputy Program Manager, NASA); and several of the Naval Air Systems Command engineering staff. Two ASTOVL propulsion engineers, [redacted] and [redacted] joined the JAST Propulsion IPT. Additional ASTOVL teams, including Concept Assessment (led by [redacted], Forces & Moments [redacted], and Weight & Balance [redacted]), were absorbed into the Program Integration & Analysis Directorate. Several USAF ASC personnel joined these teams to provide balanced service membership, but generally remained stationed at Wright-Patterson AFB.

These teams conducted an in-house "Qualitative Assessment" of the WSCs' proposed design concepts during late summer of 1995, and a more comprehensive "Quantitative Assessment" toward the end of 1995, preparatory to the release of the request for proposal (RFP) for the next phase. The purpose of these assessments was to ensure that all contractors were being consistent in their developments of the concept definitions, their common attributes, and the quoted capabilities of each. This activity was conducted in parallel on two levels of interaction with the contractors. One level focused on the areas of aerodynamic performance (a.k.a. force and moments) and weight estimation, reconciling differences between contractor and government estimates. The other level involved investigation of the contractor's design concepts and their mission analyses results. Again, this was to ensure the various concepts and quoted mission capabilities were placed in a common and consistent frame of reference for across-the-board JSF

comparisons. The design analysis activity defined the ground rules and assumptions that were provided to the contractors, to be used by them in developing their various concepts. Similarly, the mission analysis activity accomplished this same function, as well as defining a given set of mission profiles that represented an aggregate of the joint service types of operation.

A Cost Focus Team (headed by Maj [redacted]) and an Acquisition Reform & Streamlining Focus Team (headed by [redacted]) were also established within the Program Integration & Analysis Directorate, while Modeling, Simulation & Analysis (MS&A) was moved into Requirements from Program Integration & Analysis, which was then renamed Program Integration. Prior to CDP, the Weapons and Avionics IPTs in the TM Directorate were eventually merged into a Mission Systems IPT, to provide better integration in areas of possible overlap (e.g., targeting). A JAST Organizational Chart, representative of the CDDR Phase, is illustrated in Figure 26.

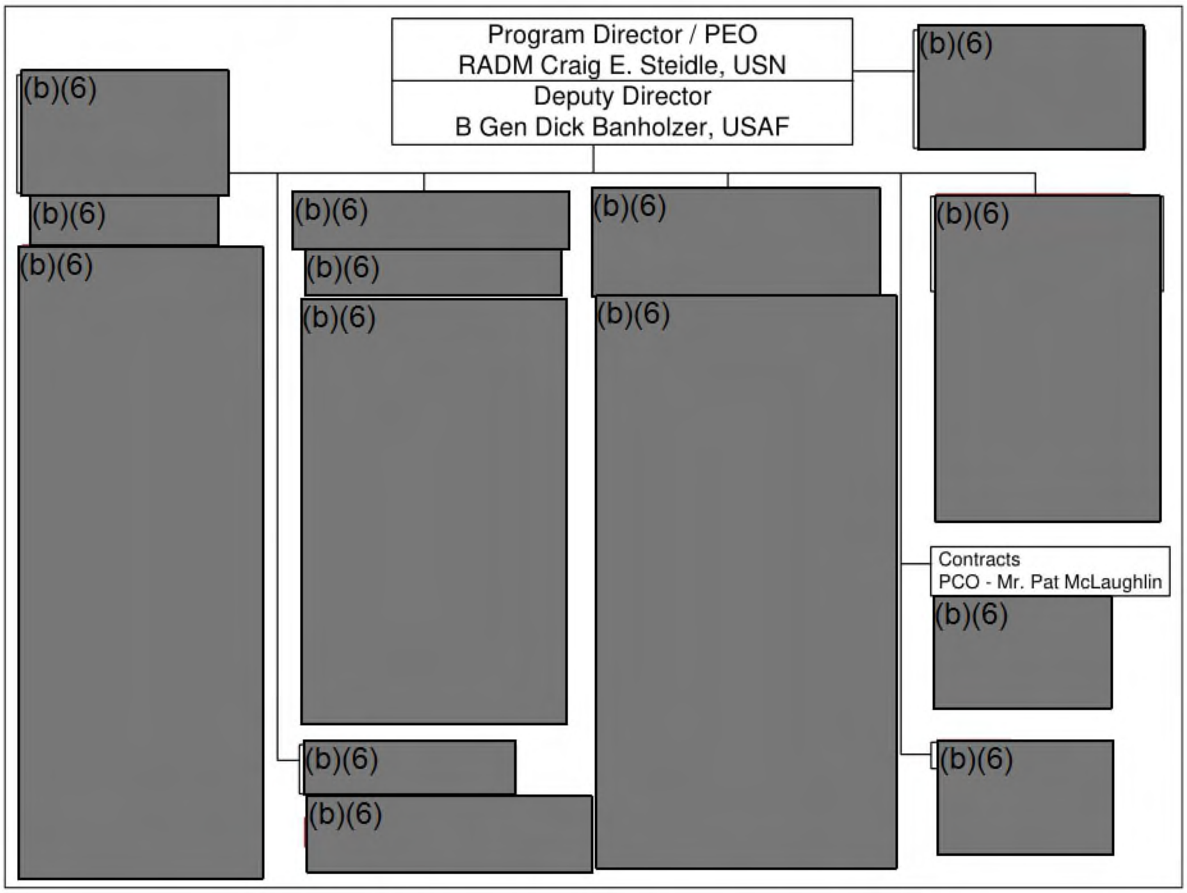

Figure 26: JAST Program Office Organization, Late 1995

4.1.5 Fall 1995 "DAB-Like" Reviews

A JAST Program Review by the Defense Acquisition Board (DAB) was planned for early September 1995. The DAB is essentially the highest-level group advising the Under Secretary of Defense for Acquisition & Technology (USD(A&T)) on acquisition milestone decisions for major DoD (ACAT I D) programs (for which the USD(A&T) is the Milestone Decision Authority). At this time, [redacted] headed the DAB. Since JAST was a non-ACAT program at the time, this was not a formal milestone review, and so it was sometimes referred to as a "DAB-like" review. The purpose was to review the plans for the coming phase of the program, prior to releasing the CDP RFP. The JAST Program Director

also hoped to resolve the issue of how to fund the now-combined, JAST/ASTOVL flight demonstration effort, which was significantly greater than what was originally budgeted for.

In preparation for the DAB-like review, the Joint Requirements Oversight Council (JROC) reviewed the program, including the newly released JIRD I, in August 1995. Following this review, the JROC strongly endorsed the JAST Program strategy and process in a JROC Memorandum (see Appendix B).

The contractors' proposed weapons system concepts, as well as the intended CDP approach, were briefed to (b)(6) [redacted] at a pre-DAB on 22 August. The "DAB-like review" was then held on 5 September 1995. At this review, which carried over into a Saturday session on 9 September, the proposed approach to the CDP was presented to the DAB.

The DAB requested additional detail in several areas, including the proposed approach to EMD phase planning, and certain cost considerations. These were addressed in subsequent reviews on 14 December 1995, and 22 February 1996, along with numerous working-level meetings, and additional reviews and briefings to other officials and agencies (Deputy Secretary of Defense, the Joint Staff, service Chiefs and Secretaries, Office of Management & Budget (OMB), OSD Program Analysis & Evaluation (PA&E), etc.). These reviews ultimately led to:

- An approved CDP plan and strategy (including approval for RFP release)
- An approved EMD phase cost estimate[4, 5]

Additionally, and very importantly, it was agreed that the flight demonstration effort should be "done right," with full-scale STOVL, CV (simulated carrier approach flying qualities) and CTOL flight testing by two competing contractor/teams. This decision was made, in principle, at a meeting with the Deputy Secretary of Defense, (b)(6) [redacted] and all of the service Secretaries (including the Secretary of the Army), on 18 September 1995. This was clearly an important turning point in the JAST/JSF Program.

Up until that time, the basic JAST funding profile had not changed from the "wedge" that was developed during the preliminary planning in 1993 (as shown in Figure 13 near the end of Chapter 2). That funding profile was suitable for small-scale technology demonstrations, but not for the design, fabrication and flight test of advanced concept demonstrator aircraft. This would require more up-front funding. To resolve the disconnect, the total funding for the CDP was increased, particularly in the "front end" (FY96-98), while the flight demonstration schedule was slipped slightly, bringing the required and actual funding profiles into agreement. DARPA and UK funding would be restored, with DARPA participation phasing out by FY99. Key Tech Mat programs would be kept intact.[6]

It is apparent from these events, that even though JAST was a non-ACAT program at that time, the program accomplished, in principle, a review process very similar to that required of a formal major acquisition program. The non-ACAT status allowed the process to be more streamlined and removed the formal documentation requirements; however, the Program Director was still fully accountable and the DoD, Joint Staff, and service principals were provided with appropriate insight on program matters.

4.1.6 International Developments

JAST effectively became an international program when it absorbed the DARPA/UK ASTOVL Program in late 1994. An MOU for that program had just been signed in August 1994, and was transferred to JAST until a new MOU could be developed. Technical discussions and formal negotiations were conducted through 1995, culminating in a new MOU signed on 20 December 1995. This MOU made the UK a Full Collaborative Partner in the JAST CDP, contributing $200 million to that phase (essentially what they would have contributed to the flight demonstration phase of the DARPA/UK ASTOVL Program). By 1996, the following countries had received briefings on the JAST Program, including opportunities for foreign participation: Canada, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, and Sweden. A full discussion of the international aspects of the JAST/JSF Program is contained in Chapter 9.

4.1.7 Program Protection & Security

During the Concept Definition Phase, the Program Protection & Security Directorate (SC) expanded to meet the needs of the Program. In addition to the Security Director, who is responsible for policy and plans, security risk management and budget/cost control, two other functional areas were represented within the directorate. The Program Protection Manager, [redacted] USN, was responsible for identifying critical technologies, performing analysis and tradeoffs, coordinating foreign disclosure and technology transfer issues, providing electronic source selection support and coordinating systems security engineering and intelligence/counterintelligence support. The Security Operations and Support (O&S) Manager, SMSgt (later-CMSgt) [redacted] USAF, followed by SMSgt. [redacted] USAF, in May 1999, was responsible for Special Access Program (SAP) execution, collateral and Sensitive Compartmented Information personnel security, visitor access, document control, communications, industrial, physical and automated information systems security issues. The JAST Security IPT was also added in February 1995 to address, integrate, and validate program protection, system security engineering (SSE), and operational security requirements, policy, and procedures in support of the JAST mission. The IPT was the primary vehicle used by the JAST Program Director to ensure security issues were integrated across the spectrum of JAST functional areas and user/operator environments and that costs were identified and contained.

After the award of BAA 94-2 contracts, (i.e., the start of CDDR), JSF security personnel visited 13 contractor facilities explaining the improved, streamlined procedures JAST would employ for the Special Access Required (SAR) technologies. By co-utilizing existing facilities, no new SAR facilities would be built to support the JAST Program.[7]

Discussions had been ongoing with the UK regarding participation in the JAST Program since mid-1994, but with the inclusion of ASTOVL in the JAST Program, the issue of foreign disclosure became an immediate additional function of the Security Directorate. In keeping with the vision of fewer government personnel, this function has largely been implemented by JPO support contractors. The foreign disclosure process is a means for controlling technology transfer and ensuring adherence to U.S. National Disclosure Policy and U.S. export laws. Integration of the ASTOVL program with JAST immediately placed an UK naval officer, CDR [redacted] in the JPO. Establishment of a formal program to regulate the transfer of JAST technologies to the UK had to be developed.

The Office of the Assistant Secretary of the Air Force for International Affairs (SAF/IA) was the designated foreign disclosure authority for the JAST Program. Under Air Force guidance, strict policies were developed regarding disclosure. Since the Program approach from inception was one of openness, the restrictions on what information could be given to which individuals created additional challenges. The JAST Program was also unique in that there was foreign participation in the developmental phases, something that had not been done before in a major program. The JPO received formal delegated authority from SAF/IA to release specific Air Force and JAST-unique information to the UK. Information originating from the U.S. Navy, or other sources, required that agency's approval for release. Internal JPO policies and procedures regarding technology release were established and a training program was initiated. A Foreign Disclosure Working Group was also established as part of the Security IPT to aid in solving the special challenges of the program. Members included Air Force, Navy, OSD, Defense Technology Security Administration (DTSA), Department of State, and industry representatives.

During CDDR, SC developed a Preliminary System Security Concept and a Program Protection Plan to transition to EMD. The SC team also worked closely with industry and government representatives to co-develop the JAST Program Security Manual and Security Classification Guides. The Program Protection team solicited industry's inputs in identifying JAST Essential Program Information, Technologies and Systems (EPITS). These represented those items that, if compromised, would result in a degradation of the combat effectiveness or decrease the combat effective lifetime of the JAST system. Additional IPT meetings were held that resulted in the co-development of program security policy and documentation; identification of security threats, which were distributed to the contractors in a Multidiscipline

Counterintelligence (MDCI) Threat Study; security requirements for an affordable, secure avionics architecture; and security cost modeling techniques.[8]

The Security Master Plan was completed in January 1996. This became the foundation for subsequent program protection efforts and was issued with the CDP RFP for use in proposal preparation. The purpose of the plan was to:

- Provide a roadmap for continued execution of a JAST Program Protection Plan
- Identify the measures necessary to protect the JAST weapon system's combat effectiveness throughout its life cycle in the most cost-effective manner
- Serve as a baseline reference document for the development and evaluation of all security related contract deliverables
- Standardize the description and intent of all JAST security product requirements
- Provide a common methodology for planning, budgeting, and tracking security-related expenditures

4.1.8 Name Change to Joint Strike Fighter, and Acquisition Category ID Decision

In March 1996, the JAST Program was renamed as the JSF Program. Concurrently, Congress began to express concern over the fact that JSF, together with several Advanced Concept Technology Demonstrations (ACTDs), were exceeding the cost thresholds for major acquisition programs, but were not being subjected to the same oversight and control as formal acquisition programs.[9] Part of the problem was simply communication. While reviews and briefings to the DAB, JROC, and other appropriate organizations and individuals had been accomplished, these were not counted as formal acquisition milestone reviews. Many observers outside the program—including Congressmen and staffers—did not realize the extent of such activity. Nevertheless, the program had evolved, and the focus had shifted away from "generic" Tech Mat and requirements analysis, towards the development of a fairly specific weapons system. As such, it was appropriate for JSF to be designated a formal acquisition system in Acquisition Category I, DoD (ACAT ID).

On 23 May 1996, [redacted] therefore notified the service Secretaries: "Effective immediately, JSF is added to the Major Defense Acquisition Programs list as a joint, DoD, Acquisition Category ID program."[10]

[redacted] did not consider it practical nor necessary to require the JSF program to *immediately* conform to all requirements for an acquisition program approaching Milestone I. He therefore directed a "tailored, phased" approach to program documentation. The resulting Milestone I documentation and decision process is described in Section 4.5 (Transition to CDP).[11]

Highlights of the CDDR Phase, in the areas of Requirements development, Technology Maturation, and Weapons System Concept development, are presented in the following sections.

4.2 Requirements

Principal requirements activities during CDDR included:

- Campaign simulations, using both legacy forces and forces including a "generic" JSF family
- Release of JIRD I in August 1995
- A second iteration of the STT process
- The first Cost and Operational Performance Trades (COPT I) report

Four "requirements pillars" also emerged, representing the most important existing deficiencies, to embody the essential JSF required characteristics:

- Survivability

- Lethality
- Supportability/Deployability
- Affordability

4.2.1 Joint Mission Area Analysis and Joint Initial Requirements Document

The fifth FPT activity was held in December 1994 at NAWCAD, Patuxent River, Maryland. This was the second JAST campaign simulation, again using legacy forces with 2010 timeframe threats and programmed weapons. However, in this iteration, the DPG scenario was Northeast Asia. Acting on lessons learned from the first campaign simulation, more preparation was devoted to development of current threat and weapons databases.

Another enhancement to the FPT process was the inclusion of logisticians as full participants. In the earlier simulations, logistics experts had participated largely as observers, noting what enhancements to the Thunder model would be required to realistically simulate logistics tasks. To provide the best possible baseline, incorporating all enhancements, the Southwest Asia scenario from the DPG was re-run in April 1995 with legacy forces at Kirtland AFB, Albuquerque, New Mexico.[12]

The first year of JAST requirements accomplishments led to a Joint Mission Area Analysis (JMAA) briefing and the JIRD I. The JMAA briefing was based on the initial campaign simulations, plus additional inputs from the warfighters in areas not addressed by the simulations. The briefing contained:

- Outlines and definitions of each service's strike mission area needs
- Common deficiencies in the performance of operational tasks
- Each service's rankings of the common deficiencies

The JMAA briefing was presented in late spring and summer of 1995, to the JROC, the JAST Executive Committee, the service Chiefs, and other acquisition and requirements principals.

4.2.2 Joint Initial Requirements Documents

JIRD I was released on 15 August 1995, and contained Desired JSF Operational Characteristics for an Initial Operational Capability (IOC) around 2010. These are listed in Table 7.

(b)(4)

[redacted]

JIRD I was signed by General Joseph W. Ralston, USAF; General Richard D. Hearney, USMC; and Vice Admiral T. J. Lopez, USN; and was endorsed by the JROC in August 1995 with the following statement (The full JROC Memorandum is included in Appendix B):[14]

> We endorse the JAST process and acquisition as a method of rationalizing competing requirements to meet joint warfighting needs. The Council believes delivering JAST in the 2007 to 2010 time frame is critical to alleviating future TACAIR shortfalls. We strongly support the JAST Program plan to date and concur with the direction and scope of the concept demonstration phase as briefed including the program's 'family of aircraft' strategy….[15]

4.2.3 QFD II

A second iteration of the Strategy-to-Task-to-Need-to-Technology analysis was performed in June-July 1995. Relative to the first iteration approximately a year earlier, QFD II benefited from the following:

- Requirements MS&A provided additional insight into campaign and operational issues and existing deficiencies.
- Tech Mat activities provided better understanding of technology/attribute linkages.
- CDDR technology roadmaps and concepts were defined, providing a clearer understanding of technology transition potential.

By this time, specific JAST Tech Mat projects had been formulated. The analysis therefore was able to provide a ranking of individual technology projects, according to their total contribution to affordability and effectiveness. To do this, an additional level was added to the QFD analysis. "Matrix F" linked specific technology projects to the technology areas in Matrix D, according to how much each project advanced the state of the art in each area. A new affordability matrix, Matrix G, replaced the earlier Matrix E and linked each technology project to affordability, according to projected LCC savings and associated investment. The final QFD II flowdown is illustrated Figure 27.

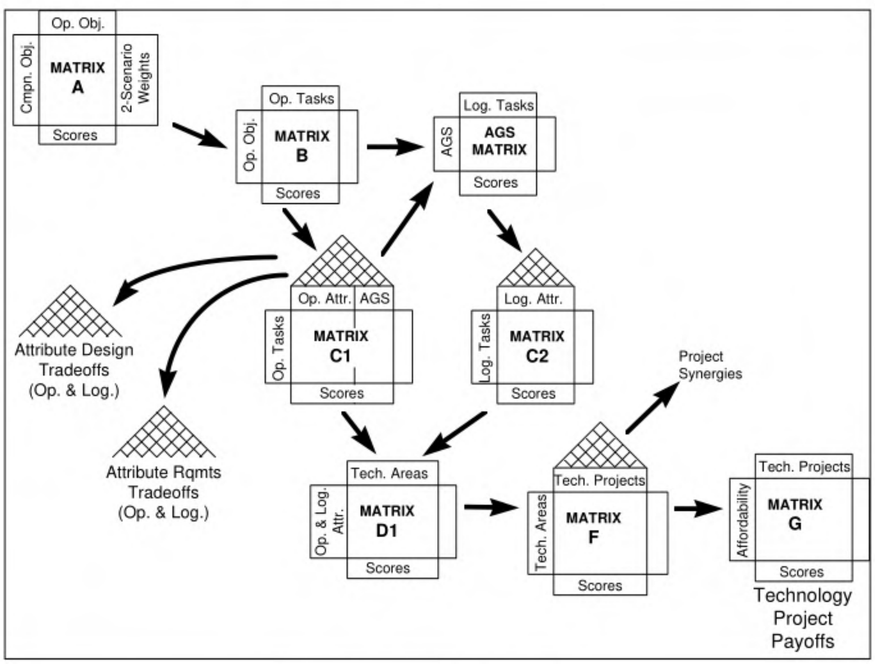

Figure 27: QFD II Flowdown

Assigning a Technical Importance rating to each of the 65 technology projects sponsored/supported by JAST—i.e., net contribution on a 100 point scale to the achievement of campaign objectives according to QFD Matrices A through F—and then averaging with each technology project's expected LCC savings from Matrix G, gives a figure of merit which balances affordability with effectiveness. The top 20 JAST technology projects according to these combined criteria are listed in Table 8.[16]

Table 8: Top 20 Technology Projects by Combined Affordability and Effectiveness

1. Integrated Core Processing (ICP)
2. JSF Integrated Subsystems Technology (J/IST)
3. Low Cost Manufacturing Program
4. Onboard Diagnostics
5. Single vs. Twin Engine
6. Integrated RF Systems
7. Advanced Lightweight Aircraft Fuselage Structures (ALAFS)
8. JAST Manufacturing Demos (JMD)
9. Tri-Service Common Airframe Study
10. Propulsion/Airframe Integration/Optimization
11. Integrated Electro-Optical/Infrared Systems
12. Affordable Fighter Aft-Fuselage Structures Technology (AFAST)
13. Manufacturing Tools
14. Advanced Strike Integrated Diagnostics (ASID)
15. Software Infrastructure
16. Organized Wiring
17. Avionics Technology Integration and Prototyping (ATIP)
18. Crew Systems Studies/Demonstrations
19. Advanced Material Demonstrations
20. Joint Service Advanced Flight Control Technology Studies/Demonstrations

4.2.4 Generic Composite Scenario Campaign-Level Wargames

The 1994 DPG contained several FYDP Illustrative Planning Scenarios (IPSs), of which Southwest Asia (SWA) and Northeast Asia (NEA) represented prototypical Major Regional Contingencies (MRCs). In support of the JAST Program, the SWA and NEA IPSs were extrapolated to the 2010 timeframe, the services and Joint Staff developed notional Time-Phased Force Deployment Lists, and the Defense Intelligence Agency (DIA) provided approved threat projections and laydowns. The initial JAST campaign simulations utilized those two scenarios in support of their first three campaign-level FPT wargames, all focused on identifying warfighting deficiencies of US legacy forces against the projected 2010 threat. As a result of these wargames and other analysis, the JAST Program identified a need for future iterations of the DPG to include a set of "standardized" long-range planning/acquisition support IPSs focused on the 2010-2020 timeframe.

Of equal importance, the JAST Program identified the need for a politically insensitive, stable long-range planning/acquisition support IPS which was "generic" in its approach but had sound statistical underpinning with regard to the quantity and quality of the threat, target set, geography, weather, etc. The JAST/JSF Program was instrumental in both the development of such an IPS – called the Generic Composite Scenario (GCS) – and gaining Joint Staff and OSD support for inclusion of GCS in the 1996 version of the DPG (renamed the Composite Longer Range Scenario (CLRS)). This allowed planners to aggregate important considerations from among the nine DPG long-range planning/acquisition support IPSs into one scenario for simulation purposes. The GCS was therefore used in JAST/JSF campaign simulations from late 1995 onward, starting in December at NAWCAD Patuxent River, using legacy forces in the 2010 timeframe.

In May 1996, the FPT met at Edwards AFB for another GCS simulation. This FPT used a force structure that included a notional JSF aircraft family for the first time. In the Thunder campaign-level model, a weapon system is described in terms of parameters representing key characteristics such as sortie generation rate, logistic footprint, signature, range, weapons employment capability, etc. This notional JSF aircraft family therefore did not represent specific aircraft designs, but rather a set of desired characteristics.

A briefing, titled "JSF Makes A Difference," was developed from the results of the two GCS FPT wargames (i.e., December 1995 with legacy forces and May 1996 with notional JSF aircraft). This served as a follow-on to the earlier JMAA briefing, and highlighted the impact of a weapon system with the desired JSF attributes operating in realistic numbers, on key campaign-level Measures of Outcome, including:

- Total movement of the Forward Line of Troops (FLOT) (i.e., the distance of enemy penetration into friendly territory before the advance is halted)

- Time to restore FLOT to previous position
- Total number of friendly casualties

The bottom line was that a strike fighter with the JSF desired characteristics would significantly enhance the U.S. armed forces' ability to carry out the National Military Strategy, i.e., winning quickly, decisively, and with minimum casualties.

4.2.5 Virtual Strike Warfare Environment (VSWE)

As discussed above, the primary MS&A activities during CDDR were still at the campaign level. However, the two Virtual Strike Environment studies conducted under BAA 94-1 led to an implementation plan for a Virtual Strike Warfare Environment (VSWE) to provide a capability for virtual, pilot-in-the-loop simulation at the engagement and mission levels.

Northrop Grumman continued their VSWE work during 1995-96 under an addition to their weapons system CDDR contract. This work included the development of interface requirements and a VSWE concept of operations. The three Avionics Virtual Systems Engineering Prototyping (AVSEP) efforts awarded under BAA 94-2 (to Boeing Defense & Space, Northrop Grumman, and Texas Instruments) were related to the VSWE. The AVSEP efforts were intended to support the VSWE by developing concepts for "virtual prototypes" of advanced avionics subsystems, which could then be evaluated in the VSWE.[17]

A preliminary demonstration of the VSWE, featuring initial virtual prototypes of each competing contractor's preferred weapons system concept (PWSC), was presented at a JSF Requirements VIP Day in August 1996 at NAWCAD Patuxent River. The VIP Day also included a System of Systems brief and a presentation of COPT I results (see below). (A letter from (b)(6) [redacted] to the JSF Program Director following this event is included in Appendix B.)[18]

4.2.6 Initial Cost and Operational Performance Trades (COPT I)

While the WSCs had performed cost/performance trade studies throughout their Concept Exploration and CDDR contract activities, the first formal COPT I was begun during the spring of 1996. This was initially referred to as an Initial Cost and Operational Effectiveness Analysis (ICOEA), however the name was changed to COPT before completion. The COPTs are an important complement to the requirements modeling and simulation process. They are the primary vehicle through which the systems engineers, cost analysts, and warfighters assess whether the desired characteristics are achievable, what they will cost, and what the cost/performance trade sensitivities are. The areas studied during 1995-96 are shown in Table 9.

Table 9: COPT I Studies During 1995–96[19]

Air Vehicle Performance Studies	Supportability Studies	Affordability Studies
• Range • Payload • Basing Flexibility • Survivability • RF Signature • IR Signature • Speed • Maneuverability • Carrier Suitability	• Logistics Footprint • Sortie Generation Rate	• Average Unit Recurring Flyaway Cost

COPT I was based primarily on a review of the cost/performance trades presented by the WSC during the CDDR phase, as they related to the requirements "pillars" of survivability, lethality, supportability and affordability. JSF Requirements staff and systems engineers reviewed the collective analyses of the contractors, compared results, and extracted conclusions that were applicable across all concepts. The

COPT I report was completed on 2 July 1996 and was the first in a continuing series of COPTs, which (in conjunction with an independent Analysis of Alternatives) will replace the traditional Cost and Operational Effectiveness Analysis (COEA) prior to Milestone II. Although the first COPT appeared after JIRD I, subsequent COPT updates have been aligned to support each successive version of the JIRD.[20]

COPT I was developed while the source selection for the forthcoming CDP was in progress (as described subsequently in Section 4.5.1). Most communication between the JPO and the WSCs was suspended during that period; however, RQ was authorized to continue their work with the contractors during the source selection. To do this without risking compromise to the integrity of the source selection, two principal precautionary measures were taken:

- RQ did not have any involvement in the source selection.
- Discussion of the weapons system designs contained in each contractor's proposal was prohibited.
- Interaction was restricted to the "IPR 3" configurations, referring to the designs presented at the last major Interim Program Review (IPR) prior to the source selection.

The COPT I trades therefore were not based on the latest available configurations. However, a much more significant consequence of the RQ's isolation from the source selection process was a lack of insight for funding COPT trades in CDP. Those knowledgeable of the COPT process were not involved in the source selection, and therefore had no input into the development of the CDP contracts.[21, 22, 23]

4.3 Technology Maturation

During the previous Concept Exploration phase, the TM Directorate focused on an initial database of 585 technology projects, to prepare a logical 5-year investment strategy. The primary "filters" to narrow down this project list were:

- Internal and contracted studies by JAST TM IPTs
- JAST QFD I from June through September 1994
- Technology priorities identified by the WSCs in the BAA 94-1 Concept Exploration studies
- Funding constraints

The result was a broad-based consensus on what technology areas offered promise of furthering JAST objectives within the JAST timeline and available funding. Specific technology projects were initiated in those areas rated highly using the above filters.

The CDDR phase brought further refinement. WSC participation on the TM IPTs facilitated a 2-way interchange: the evolving Tech Mat plans were provided to the WSCs, and the WSCs provided feedback on how well those plans supported their evolving design concepts. Technology needs were thereby refined in progressively greater detail. The warfighters were able to provide input on individual technology projects as a result of operator/maintainer representation in the TM IPTs. Additionally, QFD II in June-July 1995 (described in the previous section) extended the "requirements flowdown" to the level of individual technology projects, showing how each proposed project did (or did not) support the achievement of top-level campaign objectives and life cycle affordability.

The Tech Mat programs absorbed a big funding cut in August 1995 as a result of the FY96 budget appropriation. Rather than spread the cuts like "peanut butter" across all projects, thereby eroding the technical content of each, it was decided to preserve the most important ones and cancel the others outright. Therefore, based on the QFD II rankings, only the top 20 projects out of 65, plus one or two others, were retained.

The emerging technology projects generally fell into two broad categories:

- "Low-hanging fruit," or projects where a modest JAST investment would yield valuable near-term data and risk reduction. In these cases, the JAST investment was usually on the order of a few million dollars or less, which leveraged considerable prior S&T investment.
- Major, long-term efforts that JAST undertook to accomplish comprehensive risk reduction thereby bringing selected technologies up to readiness for EMD. Some of these programs involved a total JAST/JSF investment on the order of $100 million for the period from FY95 through FY99.

It is important to understand that many projects were initiated to form the building blocks for an affordable, effective joint strike warfare capability. A few projects in the two categories are described below. The JAST/JSF technology strategy has been continually refined in parallel with the evolving operational requirements and weapons system concepts, as well as funding considerations. Some projects were conceived and sponsored entirely by JAST, while others leveraged prior and ongoing efforts by the services, DARPA, other government laboratories, etc.

4.3.1 FY95-96 "Low-Hanging Fruit" Technology Demonstrations

X-31 Quasi-Tailless Flight Demonstration: This was the first JAST involvement in a flight demonstration. The objective was to demonstrate the feasibility of a tailless strike aircraft. Projected benefits derived from reducing/eliminating the vertical tail include reductions in radar signature, drag, airframe weight and complexity, with associated cost savings. Preliminary work for the X-31 demonstration was begun in FY94 under Navy S&T funding; JAST then funded the X-31 flight tests during FY95.

The Rockwell/Messerschmitt-Bölkow-Blohm (MBB) X-31, originally built as part of a DARPA advanced aircraft prototyping initiative, was selected as a test aircraft because of its availability, thrust vectoring, and flight control capabilities. In the flight demonstrations, destabilizing feedback to the rudder of the X-31 test aircraft was used to cancel out the directional stability normally provided by the vertical tail. Thrust vectoring was then used to re-establish directional stability and control. Various levels of vertical tail reduction were emulated in this manner. Extensive computer simulation was performed in conjunction with the flight tests to extend X-31 test data to JSF configuration.

Figure 28: Rockwell/MBB X-31

Three specific tasks were used to evaluate X-31 flying qualities:

- Precision carrier landing approaches. Directional control was achieved using thrust vectoring for nominal and offset carrier type approaches.

- Representative air-to-ground attack profiles consisting of pop-up maneuvers followed by 15° and 45° dives
- Formation flying behind an F/A-18

A total of 35 flight tests were completed in January 1995. The tests successfully demonstrated precision carrier approaches while simulating a tailless aircraft. Directional control was achieved using thrust vectoring for nominal and offset approaches while maintaining glide slope. Flight tests were also conducted for ground attack profiles consisting of pop-up maneuvers followed by 15° and 45° dives. Finally, slot formation profiles were flown with the X-31 quasi-tailless aircraft following an F/A-18 through roll doublet maneuvers.

The X-31 flight tests provided a preliminary, low-cost demonstration of the capabilities of a tailless aircraft with thrust vectoring. Several demanding flight profiles were successfully demonstrated for carrier landing approaches, air-to-ground attack profiles, and slot formation flying. The information obtained from the tailless simulations proved the feasibility of this configuration.

Shared Aperture Sensor System (SASSY) flight demonstration: This leveraged S&T project addressed shared electro-optical and infrared (EO/IR) sensors for surveillance, identification and targeting. Projected benefits include reduced cost, weight, and number of EO/IR subsystems and components, all contributing to reduced LCC. Sensor integration also supports increased survivability by reducing the number of apertures required (thereby contributing to overall signature reduction). During the summer of 1995, a 480 x 640 pixel, mid-wave IR, staring focal plane array was demonstrated aboard a P-3 aircraft. SASSY combined the functions of a forward-looking infra-red (FLIR), infra-red search and track (IRST), and television camera set (TCS) using a single, 3-inch diameter aperture. The sensor demonstrated superior air-to-ground target discrimination capabilities in both daytime and night conditions.

Wideband integrated forebody demonstration: The MIRFS effort (described subsequently in Section 4.3.2) benefits directly from this BAA 94-2 effort by Hughes. The objective was to address low observable and radio-frequency (RF) antenna performance risks associated with a wideband radome and array appropriate to the JAST mission. In addition to meeting the desired RF performance criteria, the demonstrated radome achieved excellent RCS performance, thereby reducing the risk of the MIRFS effort by proving a wideband integrated forebody.

Integrated Helmet Audio-Visual System (IHAVS) flight demonstration: The Objectives of the IHAVS program were to demonstrate improved survivability and lethality for a single-crew strike aircraft through reduced pilot workload and increased situational awareness (SA). This was accomplished by integrating several helmet-mounted audio and visual technologies, each of which had been individually demonstrated before.

Figure 29: AV-8B Pilot with IHAVS

Initiated in February 1995, IHAVS components include a GEC Viper II binocular helmet-mounted display (HMD) system, a Polhemus helmet tracker, a USAF Armstrong Laboratory 3-D audio system with active noise reduction (ANR), a Smiths Industries Interactive Voice Module (IVM), and a Lockheed Martin Aeronutronics NITE Hawk Self-Cooled FLIR Targeting Pod (TPOD). Aircraft integration was performed by McDonnell Douglas Aerospace and Naval Aviation Warfare Center/Weapons Division (NAWCWD) China Lake, California. Twenty-five flights of an IHAVS-modified TAV-8B were successfully completed from 30 September 1995 through 13 June 1996. Three test pilots, one from the Marine Corps, Air Force, and Navy, flew realistic air-to-ground missions against targets of opportunity.

IHAVS enabled the pilots to improve threat avoidance, conduct multiple sequential target acquisitions during attack, and perform simulated weapons deliveries. Areas requiring additional development were also identified. Specifically, the flight testing of the integrated system revealed issues associated with the impact of a realistic operating environment—noise, G's, vibration, etc.—on the system's performance, including the accuracy of the head tracker and the reliability of the interactive voice module. Helmet weight was also found to be an important issue. Overall, the integration of IHAVS technologies, and their resultant synergism, demonstrated the potential to increase pilot SA while reducing workload during a strike mission. The teamwork and cooperation of joint government and industry organizations was a key factor in the success of the IHAVS demonstration.

J-1000 Improved Lethality Munition demonstration: Early JAST concept studies identified internal weapons bay size as a major driver of airframe size, weight and cost. Although 2,000 lb. weapons have historically been required to successfully attack hard targets, the J-1000 project demonstrated an enhanced lethality concept for a 1,000 lb.-class weapon through improvements in penetration and blast/fragmentation. The Air Force led the penetration effort, culminating in a sled test at Eglin Air Force Base, Florida. In this test, a 1,000-lb. bomb body penetrated a reinforced concrete blockhouse and emerged intact, demonstrating superior hard-target penetration capability. The Navy managed the enhanced blast/fragmentation portion of the J-1000 project. J-1000 goals were met, demonstrating comparable lethality of an improved 1,000-lb. class weapon to existing 2,000 lb. munitions.

Boeing/Dassault Airframe Commonality Study: While this effort does not exactly fit the mold of a "demonstration," it is noteworthy because a modest JAST investment was able to gather quantitative

engineering data in a very high-leverage area: airframe commonality. The project also provided a valuable early experience for JAST with foreign participation at the subcontractor level. Boeing chose to work with Dassault Aviation of France on this project, because of Dassault's proven design capability and experience with the dual-service Rafale strike/fighter aircraft. (Dassault also developed the CATIA computer-aided design/computer-aided manufacture (CAD/CAM) program, which is now used extensively by Boeing and elsewhere in U.S. industry).

The Airframe Commonality study consisted of two parallel efforts, a contracted study awarded under BAA 94-2, with Boeing Defense & Space as prime contractor and Dassault as a subcontractor; and a government study conducted by a joint Air Force/Navy team. Both efforts were begun in early 1995.

The Boeing/Dassault study used an early Boeing trade study configuration to trade levels of airframe commonality against cost and weight. The approach started with a fully common tri-service airframe that met all CTOL/CV/STOVL requirements, and progressively reduced the level of commonality while re-optimizing the structure. The Dassault "Elfini" structural optimization program was used.

The government study complemented the Boeing/Dassault effort, looking at material systems, design criteria, operational requirements, technologies, and manufacturing concepts that could impact the feasibility of the common airframe design approach. The combined studies contributed to an improved understanding of the penalties for commonality by identifying:

- Which design criteria were the weight and configuration drivers
- Where it made sense to relax the level of commonality
- What technologies and concepts had the highest potential payoff for weight/cost reduction in a tri-service family

The effort was completed in May 1996. As with most other Tech Mat projects, the results of this study were made available to each of the JAST WSCs.

Manufacturing Affordability Development Program (MADP): In cooperation with industry, MADP organized a team of manufacturing engineers to visit various industry sites to identify, through a bottoms up approach (i.e., interviews with artisans/floor managers, observation of production processes, etc.), production inefficiencies and cost drivers. Surveys, conducted at the rate of one a month from March 1995 through March 1996, covered a total of 17 sites at 12 major airframe, engine and avionics companies, as shown outlined in Figure 30. Following each visit, the data was analyzed and a company-confidential report was provided to that site with recommendations for improvements. Upon completion of the whole project, a final report was developed highlighting "best practices," as well as areas that would benefit from additional manufacturing process initiatives. The report was presented to industry at a JSF Manufacturing Day in August 1996. The MADP results are being used to formulate follow-on manufacturing efforts.

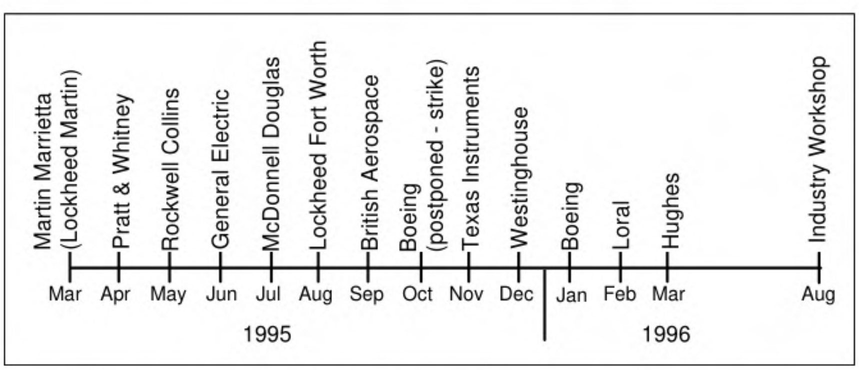

Figure 30: Manufacturing Affordability Development Program Timeline

JSF Manufacturing Capability Assessment and Toolset (JMCATS): The JMCATS program contract was awarded to General Research Corporation (GRC) in 1995 to improve the Air Force's Manufacturing Capabilities Requirements (MCR) Assessment Methodology. GRC identified specific extensions, enhanced the assessment methodology, and developed a computerized toolset to facilitate its utilization. These extensions potentially enable the JSF Program to objectively assess the maturity and risk of the manufacturing technologies and allow an IPT to identify the need for design changes or process development activities early in the product development process. In 1996, the JMCATS approach demonstrated the capability to identify and resolve key process parameters associated with the F-22 missile launch detector.

4.3.2 Major Technology Demonstration Programs Initiated During CDDR

JAST (Now JSF) Integrated Subsystems Technology (J/IST): Traditionally, aircraft utility subsystems have been designed separately, resulting in several inefficiencies. Engineers have focused on making the lightest, smallest cooling systems, the lightest, smallest heating systems, the lightest, smallest auxiliary and emergency power units (APU and EPU), etc. Because this approach optimizes at the component level, it is costly. Waste energy that could be used by another subsystem is dumped overboard; and hardware components that could be shared (e.g., heat exchangers) are instead duplicated. Eliminating such inefficiencies by conducting vehicle-level, rather than subsystem-level, design and optimization can produce significant benefits, including reduced aircraft weight and drag, reduced subsystems parts count, improved reliability, and reduced logistics footprint. All actions would contribute to significant reductions in LCC.[24]

In early 1994, Wright Laboratories issued a BAA for studies of vehicle utility power, controls, and subsystems integration. Lockheed and McDonnell Douglas responded to the BAA, and were awarded approximately $1 million each (jointly funded by JAST and Wright Labs) for the 18-month Vehicle Integration Technology Planning Studies (VITPS).

Early VITPS results identified two ongoing S&T programs—More Electric Aircraft (MEA) and Subsystems Integration Technology (SUIT)—as offering significant LCC benefits. The BAA 94-1 JAST Concept Exploration results and the QFD I results confirmed the desirability of maturing SUIT and MEA technologies. In August 1994, when JAST Tech Mat efforts, as well as the Air Force SUIT and MEA programs, were affected by Congressional FY95 budget cuts (described earlier in Section 4.1.2), JAST formulated a single program to advance these technologies in an integrated fashion. The JAST Flight Systems IPT chartered a team consisting of Wright Laboratories SUIT and MEA personnel, along with a deputy program manager from the Navy, to manage the JAST Integrated Subsystems Technology (J/IST) Demonstration Program.

JAST BAA 95-3 was released in the spring of 1995, soliciting proposals for an expected $100-million, four-year demonstration program. As usual, the source selection was performed electronically, including the most detailed technical evaluation performed up to that time in the JAST Program: over 40 technical experts were involved. The flexibility of the BAA—in particular the "severable tasks" feature allowed the source selection team to select the best provider for each element of the planned effort. A side benefit was that the resulting awards included all of the JAST WSCs, thereby insuring maximum interchange and fair opportunity to transition the technology into weapons system concepts. Three separate, but interrelated contracts, totaling $114 million, were awarded on 22 September 1995 as follows:

- Lockheed Martin—Electric power generation/distribution and electric actuation flight demonstrations
- McDonnell Douglas—Thermal/Energy Management Module (T/EMM) and electric power and actuation ground demonstrations
- Boeing—Vehicle level cost/benefits analysis

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Major subsystems suppliers were included as subcontractors to the WSCs. The majority of the advanced technology components to be demonstrated in J/IST were developed under previous SUIT and MEA contracts, and the subsystem suppliers from those efforts were logically chosen by the WSCs as participants in the VITPS and J/IST efforts. The teaming arrangements and working relationships formulated in the VITPS phase have led to excellent cooperation in the J/IST Program.

(b)(4)

Figure 31: AlliedSignal Aerospace T/EMM System

The integrated subsystems architecture includes a T/EMM (see Figure 31), which combines the functions of a traditional aircraft auxiliary power unit, emergency power unit, and environmental control system. With the T/EMM configuration, the number of subsystem parts and bay volume requirements are significantly reduced. The other major part of the J/IST architecture is a fault tolerant 270 VDC electrical power generation, management, and distribution system powered by an engine–driven, dual-channel, switched reluctance starter/generator (S/G), shown in Figure 32. This system powers electrohydrostatic actuators (EHAs) that replace traditional hydraulically actuated flight controls.

Figure 32: Sundstrand Corp. Dual Channel Switched Reluctance Starter/Generator

On current strike aircraft, power to the flight controls is provided by a central, high-pressure hydraulic system. Maintenance of hydraulic systems requires significant maintenance effort and aircraft downtime. This entails:

- Equipment to drain and refill the aircraft hydraulics system
- Storage and disposal of old hydraulic fluid
- Maintaining a supply of replacement hydraulic fluid

Hydraulic systems operate at pressures ranging from 3,000 to 5,000 psi. Such high-pressure lines weep frequently, especially as they age. If they are not repaired immediately, they burst and the hydraulic system fails. In the event of battle damage, leaking hydraulic fluid is a major cause of in-flight fires. With the EHAs (shown in Figure 33), in contrast, all hydraulics will be self-contained within each actuator, which can then be individually replaced as LRUs. The central hydraulics and airframe mounted accessory drive (AMAD) systems may be eliminated, providing reduced vulnerability and eliminating the need for hydraulics ground servicing capability.

(b)(4)

[redacted]

Figure 33: F-16 High-Horsepower EHAs by Parker Bertea Aerospace (left) and Moog, Inc. (right)

J/IST technical communications and management are accomplished by industry-led IPTs. Industry IPT members include all of the WSCs plus numerous subsystem vendors. A small, dedicated Government management team headquartered at Wright Laboratory executes contract management functions on behalf of the JSF Flight Systems IPT Lead. Government experts contribute their knowledge and technical insight, but do not function in an oversight capacity. JSF Requirements representatives provide guidance in the benefits assessment and in assuring that supportability is adequately addressed.

During FY96, the J/IST program refined its consensus subsystems architecture and risk reduction plan, which included 57 specific risk reduction events, of which approximately half were hardware demonstrations. These events were to begin with component-level demonstrations and culminate in four major integrated demonstrations. The major goals for the program, to be completed by the end of the JSF Concept Demonstration Phase, are as follows:

- AlliedSignal Aerospace will conduct T/EMM ground demonstrations, with simulated engine interfaces.
- Northrop Grumman Corporation will complete critical demonstrations on 270 Volt DC electrical power system integration, high horsepower (JSF-sized) EHAs built by Moog, Inc., and two separate switched reluctance starter/generators built by Sundstrand Corp. and AlliedSignal Aerospace.
- Lockheed Martin will conduct ground and flight testing of a modified F-16 aircraft with its primary hydraulic system replaced by electrical power system components. This replacement system will include the dual-channel switched reluctance starter/generator built by Sundstrand Corp., and a three-axes, power-by-wire electric flight control system with EHAs built by Parker Bertea Aerospace.

- A team of Boeing-St Louis, Pratt & Whitney, AlliedSignal Aerospace, and Northrop Grumman Corporation will demonstrate the integrated operation of the T/EMM and an F119 engine. This demonstration will include the T/EMM, the starter/generator, fan duct heat exchangers, and a thermally efficient fuel pump.

J/IST embodies many important aspects of the JAST Tech Mat philosophy, and has become a "model" program for other efforts by the Flight Systems IPT and the JAST/JSF Program as a whole. The progress against these goals is presented in Section 5.3.1.[25, 26]

Multifunction Integrated Radio Frequency Systems (MIRFS): One key shared interest of the WSCs that emerged from the Concept Exploration phase was the pursuit of a low-cost, lightweight nose array—a multifunction aperture (MFA)—that provides the transmit/receive function for selected radar, electronic warfare (EW) and even communication/navigation/identification (CNI) modes. In current fighter aircraft, the radio-frequency (RF) systems and associated support electronics account for nearly 60% of the avionics flyaway cost. The aperture(s) alone typically represent 19% of the avionics cost.

The heart of MIRFS is an active electronically scanned array (AESA), consisting of a matrix of many small transmit/receive (T/R) modules. Beam steering is accomplished electronically rather than mechanically, thereby providing a high degree of beam forming agility. The multitude of T/R modules provides for easy maintenance and "graceful system degradation" as individual modules fail. In current phased array antennae, while shifting is performed at each antenna element, the signal originates from a central transmitter. This is often the single point of failure for the whole system.

The F-22 will be the first production fighter to utilize an AESA, and JSF will build on this investment in AESA technology. Relative to the F-22 aperture, JSF will require the following additional or improved features:

- Lower T/R module cost
- Lighter weight
- Reduced power and cooling requirements
- Wider bandwidth for air-to-ground radar plus some electronic warfare and CNI functions, in addition to air-to-air radar

Air-to-ground modes are necessary for the JSF's primary missions. The integration of EW and CNI tasks, traditionally performed by separate hardware, will produce further improvements in reliability, logistics footprint, and integration on a low observable airframe.[27]

The MIRFS program was established to reduce EMD risk for a low-cost, lightweight MFA that would meet these requirements. Crucial to the success of this effort was the emphasis on a demonstration focused to the WSCs' needs. Their priorities were: first, the effort should include two vendors. While the MIRFS effort would not be a formal competition, the use of two vendors would spur innovation, drive down costs, and allow the winning JSF prime contractor to select the MFA vendor who demonstrated the most cost-effective design that best matched the prime contractor's needs. The second priority was that the demonstrated designs should be based on an integrated RF system concept, fully supportive of the evolving JSF concept of operations. Third, the vendors should each build a *full-scale* MFA and ground test it using stressing modes. The final priority was to perform flight tests of the MFA in these same modes.

Using these needs and priorities as guideposts, the JPO developed and released BAA 95-4 to solicit proposals. This BAA differed from all previous avionics solicitations in the following ways: First, it was far larger, involving two five-year contracts expecting to total over $105 million. Second, it specified in detail what was expected of the demonstrations. Third, offerors would have to include each of the JSF prime contractors as a subcontractor as part of the proposal and execution to ensure their MIRFS concept retained a focus on the prime contractors' needs. Previous BAAs had merely expected associate contractor agreements between these parties—sometimes with disappointing results. The MIRFS arrangement created

the odd, but not unheard-of, situation of the WSCs playing the dual roles of supplier and customer. Nevertheless, the parties involved understood and agreed with the underlying objectives of this relationship.[28]

Two contracts, totaling $110 million, were awarded in February 1996 to Hughes Aircraft Company, and Northrop Grumman Electronic Sensor Systems Division (formerly Westinghouse). The MIRFS program is divided into three phases, as detailed below:

- Phase I: MIRFS Concept Definition (completed in FY96)
  - Defining the role of the multi-function aperture (MFA) in the Preferred Weapon System Concept (PWSC) integrated RF system
  - MFA requirements definition, concept definition and design
  - Cost-effectiveness analysis
  - Manufacturing plan

- Phase II: MFA Integration and Ground Demonstration (FY97-99)
  - Transmit/Receive Module Manufacture
  - Phenomenological model delivered to WSCs for PWSC integration
  - MFA sub-array and full array buildup
  - Ground demonstration of resource management and key MFA modes

- Phase III: Flight Demonstration (FY99-00)
  - Array functionality
  - Key modes

Integrated Sensor System (ISS): ISS was initiated by the Air Force Wright Laboratories (WL) prior to the start of the JAST Program. The objective of ISS is to integrate the "back-end" radar, EW and CNI processing functions. Because this complements the JAST-sponsored MIRFS project discussed above, JAST joined the ISS effort and provides a portion of the funding. Key technologies being matured under this effort are shared, common processing resources and high-speed switching. Two teams, one led by Lockheed Martin and one by McDonnell Douglas (now Boeing Aircraft & Missiles in St. Louis), are executing the ISS effort.[29]

Integrated Core Processing (ICP): The majority of signal processing on a tactical aircraft is concerned with taking the continuous streams of high-throughput data from the sensors, and processing them for display in a coherent, intelligible format, to the pilot. Core processing typically accounts for about 20% of avionics flyaway costs in a fighter. The ICP project focuses on demonstrating hardware and software features necessary to achieve an affordable, common, JSF avionics suite. It is intended that the Air Force, Marine Corps and Navy JSF avionics suites should be at least 95% common. ICP will contribute to JSF affordability by enabling and/or enhancing the following characteristics:

- Open systems avionics architecture
- Hardware and software reuse
- Information fusion and management for effective single-crew operation

In 1960, DoD made up 80% of the national market for integrated circuits. By 1995, that market share had declined to 1.5%.[30] DoD recognizes that it is no longer the primary driving force behind the electronics industry. Military avionics must therefore follow commercial technology. To facilitate this process, DoD is moving away from dictating standards and specifications to industry, and is instead seeking to use or adapt accepted commercial standards and design practices. Concurrently, avionics developers are driving towards a higher degree of integration, to reduce the number of unique hardware components and optimize the processing capability aboard the aircraft. The JSF avionics architecture will build upon the Pave Pillar program, which developed the integrated avionics concepts and architecture of the F-22.

The ICP concept calls for most digital data processing, cockpit display generation, and other computationally demanding tasks to be concentrated in a shared, fault tolerant, and very high performance ICP area using shared resources. Some raw signal processing and analog-to-digital conversion, as well as certain tasks that require very short delay times (such as encrypted communication), will be performed locally by dedicated electronics co-located in an aperture. In most cases, the output of such localized processors will then be sent to the core processing area where it will be used to support the total weapon system operation and/or the development of an overall situational awareness "picture." An important feature of the desired avionics architecture, is that the system designer can determine which type of processing is appropriate for each task, and transparently combine centralized and distributed processing to optimize performance and cost. Unique hardware will be minimized, and most processing—whether centralized or distributed—will be accomplished with a small set of common hardware building blocks.[31]

Open systems architecture provides for an affordable avionics suite with significant growth capability, and cheaper/quicker upgrades than traditional avionics architecture. Obsolete parts will be able to be replaced while retaining the overall architecture of the system, including the software. This will reduce dependence on specific suppliers and/or components that may go out of production during the life cycle of the weapon system. Use (or adaptation) of accepted commercial standards and commercial processing and network capabilities, software portability, and demonstrations of advanced manufacturing and packaging will all contribute to an affordable open systems architecture.

Several FY95-96 Tech Mat projects were conducted in support of the overall ICP effort, including: Scaleable Coherent Interface / Real Time (SCI/RT) studies, Very High Speed Optical Networks (VHSON) effort, and a Scaleable Multi-Processor System (SMPS) study.

As with the MIRFS project, the ICP technology demonstration strategy was based extensively on WSC feedback. In contrast to the MIRFS effort, in which the prime WSCs were willing to accept a sensor vendor leading the effort, the primes were adamant about the need to head up the ICP demonstration effort themselves. Their rationale was that the core processing concept is inseparable from the weapons system concept; the design implementation and detailed trades could only be made in the context of the overall system design.

Consequently, the Avionics IPT elected to apply the budgeted ICP funding to the WSCs. Phase I efforts, prior to the CDP downselect, focused on the definition of attributes for an open-systems architecture, and initiated early studies and demonstration of the technologies.

Phase II implements specific concepts and continues with major integrated demonstrations by the two remaining WSCs, following downselect. A "gentleman's agreement" was reached in which the two primes, in the forum of the ICP sub-IPT, would use the funds in risk reduction efforts for areas of concern common to both and share the results of these demonstrations. Demonstrations specific to a single WSC would be not be funded under the ICP effort, but instead under the WSCs' main CDP contracts.[32, 33, 34]

Avionics Virtual Systems Engineering Prototyping (AVSEP): This effort, introduced in Section 3.3.5, was part of the JAST Avionics vision from the beginning of the program. Three AVSEP contracts were awarded through BAA 94-2: Boeing Defense & Space, Northrop Grumman, and Texas Instruments (subsequently acquired by Raytheon). The goal was to establish, at the weapons system level, a virtual systems engineering process for generating and refining an affordable avionics concept. This goal would have been best accomplished by awarding the AVSEP contracts to the weapons system prime contractors, with avionics vendors as subcontractors.

However, JAST was at the time more focused on technology "building blocks" than on total weapons systems. Furthermore, BAA 94-2 encompassed many efforts in other areas besides avionics. Rather than each IPT having the primary authority to determine the award(s) in its area, a single source selection panel was responsible for all of the awards. In the rush to get the BAA released (and later, to complete the source

selection) on schedule, the detailed concerns and intentions of each participating IPT were not always adequately represented. Furthermore, the total value of contracts awarded in each area did not necessarily correspond to the funding provided by each IPT. The IPTs learned from this experience, and generally released their own BAAs for subsequent efforts to better meet their specific needs.[35, 36]

Concerning the AVSEP efforts, the flexibility of the BAA process allowed anyone to propose, and deciding in advance who should receive the contracts was not considered to be in line with the JAST Program's philosophy. "Consequently," according to Lt Col [redacted] Avionics IPT Lead at the time, the AVSEP contracts "worked very well for Boeing, moderately well for the MDA/Northrop team (MDA had the lead for avionics, but Northrop had won the AVSEP contract), and poorly for Lockheed [as a subcontractor to TI, although TI tried to accommodate them as well as possible within the constraints of the contracting arrangement]." Nevertheless, the efforts as a whole provided an improved understanding of the power and limitations of the avionics virtual prototyping process, fruitful cost-performance system-level trades across avionics subsystems, and the beginnings of the virtual modeling and simulation aspects of the concept. In the subsequent CDP, the prime WSCs have assumed the leadership of the continuing AVSEP process.[37]

Structures & Materials Programs: Three major, multi-year Structures & Materials Tech Mat programs were initiated at the beginning of the CDDR Phase: Advanced Lightweight Aircraft Fuselage Structure (ALAFS), Affordable Fighter Aft-Fuselage Structures Technology (AFAST), and Inlet Duct, Edges, and Front Frame (IDEFF).

Traditional aircraft structural design practices are based on the use of metallic materials. This has typically resulted in a large number of sub-components and sub-assemblies that must be fastened together to form the larger airframe structure. Part-for-part replacement of metal with composites may achieve small weight savings in the replaced parts, but greater advantages could be achieved by designing whole assemblies of composites. In particular, the use of "unitized composites"—large composite structures, fabricated as one piece or possibly as a few pieces bonded together—to replace entire assemblies of smaller metal parts could eliminate the need for thousands of mechanical fasteners along with associated weight and production cost savings. Fasteners introduce stress concentrations (contributing to fatigue) and are vulnerable to corrosion. So their elimination can lead to improved supportability and durability of the airframe.

ALAFS sought to achieve these higher-level benefits by conducting a "clean-sheet" design effort on a section of the F/A-18E/F aircraft that combined the center fuselage and inner wing structure as an integral airframe assembly. The intent was to bring about a major change in the design and production of this weight-critical airframe structure. ALAFS was envisioned as a primarily composite, center fuselage/inboard wing section fabricated and assembled using advanced, low cost manufacturing technologies. Specific goals were to reduce the cost of that section of the aircraft by 30% and the weight by 20%. The program was structured to support an option for the ALAFS contractor, McDonnell Douglas, to incorporate it into the F/A-18E/F during production, subject to a favorable assessment by the F/A-18 Program Office.

AFAST followed a similar approach, but concentrated on issues specific to the aft fuselage region of a fighter—in particular, the high temperatures around the engine. Specific technical issues involved high temperature joints and seals, high temperature composites, improved casting and welding technology, high temperature radar absorbent structure (RAS), and improved durability and damage tolerance of high temperature components. A Lockheed/Boeing team was selected to develop a new F-22 aft fuselage design with a 15% cost savings and 8% weight reduction relative to the baseline design for that section of the airframe.

IDEFF focused on the signature-sensitive frontal areas including the engine inlet duct, edges, and engine front frame. The project aimed to transition developed technologies that offered the opportunity to

achieve signature performance similar to the "first-generation" very low observable (VLO) aircraft such as the F-117A and the B-2, but with greater supportability and at reduced cost.

However, both AFAST and IDEFF were cancelled, along with many other JAST Tech Mat efforts. Each of these programs were periodically reviewed to ensure support for JSF goals and applicability to both of the WSCs. Both programs were ultimately terminated because they no longer satisfied the latter conditions. ALAFS was cancelled, for similar reasons, in 1997.

Virtual Manufacturing (VM)/Simulation Assessment Validation Environment (SAVE): VM simulates the manufacturing process so that product designers can include producibility in their design decisions. Virtual prototypes can be "assembled" in simulation to reduce design errors and verify assembly procedures. Computerized models of humans can be used to evaluate and improve the human factors aspects of an intended assembly process. Three-dimensional factory floors and production lines can be simulated to maximize efficiency. The results are reduced cost, cycle time, and waste, at every step from design through final assembly of a product. VM accomplishes all of the above without the cost and time of building physical mockups and/or prototype tooling. All of the JAST WSCs, as well as many aerospace subcontractors and vendors, have invested considerable resources in computer modeling tools for designing products.

VM was identified early on by the JAST Manufacturing IPT as a key technology to reduce the cost of a weapons system. The VM Fast Track demonstration project in August 1995 was initiated as an early demonstration of the benefits of VM. In this demonstration, McDonnell Douglas (MDA) used prototypical VM technology, supported by commercially available software, to redesign an F-15E mid-fuselage structural frame. The part was designed in St. Louis, and all necessary adjustments to the assembly jig were made during the design process. The design—in the form of numerical-control (NC) machine instructions—was transmitted electronically to the vendor (Remmele Engineering Inc., Minneapolis, MN), who manufactured the part and then shipped it back to St. Louis, MO for assembly. The part fit the first time, without the usual iteration process of adjusting the jig and/or modifying the part. The new frame design is scheduled to be incorporated in the next F-15E block upgrade. The Fast Track demonstration provided confidence to proceed with the SAVE program.

The first SAVE demonstration was accomplished in June 1996 using an initial integrated design/manufacturing architecture and contractor-modified set of tools. This demonstration used historical F-16 redesign data as a baseline. The SAVE "core set" of integrated tools was then used to perform the same redesign tasks within a virtual design/manufacturing environment. Cost data was compared to the historical information, showing a significant savings. This was followed by a highly successful hands-on demonstration to government and industry manufacturing experts at the August 1996 Defense Manufacturing Conference (DMC). Subsequent SAVE efforts will focus on integrating the demonstrated SAVE architecture into the WSCs' design/manufacturing processes.

VM methods are being applied not only to the JSF airframe, but also to engines and avionics components such as T/R modules and processors for the AESA radar. Key technologies developed under the DARPA High Density Microwave Packaging (HDMP) and Rapid Prototyping of Application Specific Signal Processors (RASSP) programs were leveraged for incorporation into the core SAVE system.

While VM does not eliminate the need to build physical models for engineering purposes such as wind tunnel, propulsion system, structural, and radar cross section testing, it does reduce or eliminate the need for manufacturing models and mockups. VM also has potential for maintenance modeling and virtual training. The same tools and databases that permit a designer to build an aircraft in a virtual environment could be used to perform virtual maintenance, support, and repair operations on that aircraft. Recently, the JSF Supportability and Requirements Directorates have started a joint Maintainer-in-the-Loop (MxITL) initiative that will explore virtual maintenance and other opportunities to reduce operating & support costs of the JSF (see Section 5.2.9).

Joint Visual System Operational Evaluation (VIS-EVAL): In March 1996, the Supportability and Training IPT initiated a two-part, multiyear training research effort including USAF, USN, and USMC pilots. The first training evaluation was conducted on the Advanced Fiber-Optic Helmet Mounted Display (AFOHMD) developed by CAE Electronics, Ltd. It was found to have several significant improvements over earlier versions. Results and discussions indicated that aircraft air-to-ground tasks were trainable with the helmet, although issues such as helmet and display weight, fiber optic bundle restrictions, and helmet slippage will require further improvement. The second evaluation was on the Visual Integrated Display System (VIDS) developed by McDonnell Douglas (now Boeing). The primary purpose of the study was to determine trainability of tactical mission tasks using available visual display technology through a large Field-of-View display of both background and other aircraft imagery. The evaluation revealed the improvements necessary to background imagery for low level navigation, ground target identification and other low-altitude tasks.

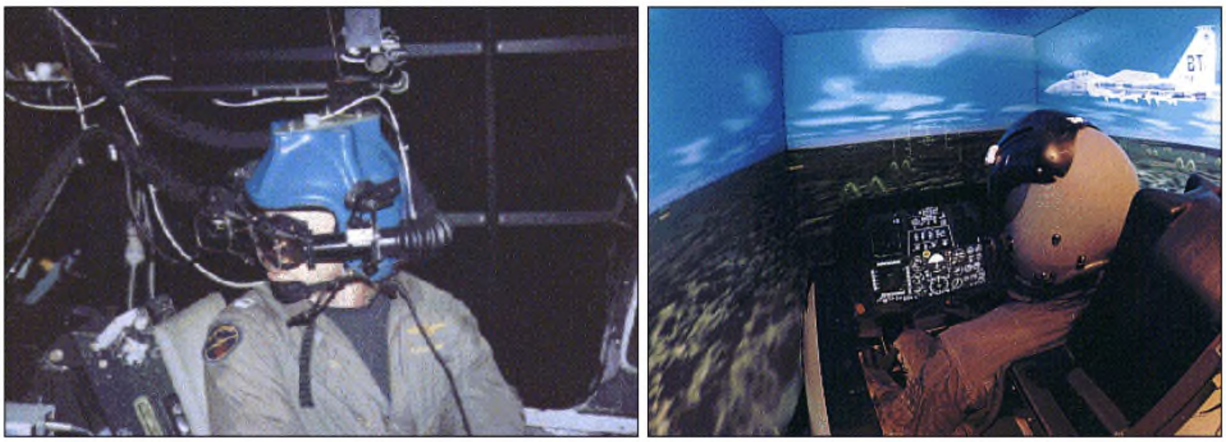

Figure 34: VIS-EVAL Efforts AFOHMD (left) and VIDS (right)

Joint Paintless Aircraft Program (JPAP): The objective of JPAP is to quantify the benefits (e.g., weight, maintenance hours, and support costs) expected by replacing traditional aircraft paint with pliable polymer appliqués attached by pressure-sensitive adhesives. The appliqués are formed into either precut gores (flat patterns) or "boots" for complex curved areas of the aircraft, such as inlet lips, where gores are impractical.

Currently, paint on military aircraft is touched up frequently for corrosion control purposes, especially in a maritime environment. Scratches and "dings" are particularly common during rough/unimproved field operations or shipboard handling in the cramped spaces on the hangar deck, but may also occur even under the best conditions. Military aircraft also require complete repainting rather frequently. To withstand the harsh tactical aviation environment of temperature extremes, supersonic flight, and normal wear and tear, aircraft paint must be fairly heavy and very durable. Consequently, powerful chemical strippers must be used to remove it, requiring painting crews to use special equipment and wear protective clothing. Disposal of the byproducts of stripping and painting has environmental impacts, which further add to the support costs. Appliqués therefore can eliminate many of these problems and substantially reduce the quantity of hazardous materials used. The bottom line is improved supportability, smaller logistic footprint, and lower LCC.

In support of developing new technologies that could reduce costs, reduce hazardous materials, and improve fleet supportability for the JSF and possibly many other applications, the JSF program office released an RFP to industry on May 1995. A contract was awarded to Boeing on 30 June 1995 to explore appliqué material concepts with specific emphasis for applications to tactical military type aircraft. JSF personnel worked with the Boeing and 3M companies to develop and flight qualify several appliqué

materials, adhesives and edge sealants capable of withstanding the operating environment of a supersonic military tactical type aircraft.

Following a series of laboratory qualification tests at Boeing, initial flight qualification of appliqué materials was conducted during September 1995 to August 1996 on a-Boeing owned and operated T-33 subsonic trainer aircraft. Concurrently, Boeing conducted laser mapping of a NAWCAD Patuxent River F/A-18 test aircraft to develop a computer model for sizing and layout of appliqués for future JPAP flight-tests. Small samples of appliqué materials were then installed on an F/A-18A external fuel tank and on 25 April 1996 flown to evaluate adhesion and peel characteristics at supersonic speeds. The large fuel tank samples and other samples installed over rough skin areas showed no peeling or disbonds, even at Mach 1.63. The pre-peeled samples broke off or frayed, but only back to the sealed edge. A scraped sample showed no increase in the size of the scrape and no peeling along the scraped edge.

From May to November 1996, larger samples of appliqué materials were installed on various skin surfaces of the F/A-18A test aircraft. Dedicated maneuvering loads test flights were completed and additional flight exposure gained through chase and training flights with the test aircraft for a total of 34 flights (51.9 flight hours). Maintenance and support procedures also developed. Planning was also begun for testing an F/A-18B aircraft with near-complete coverage (discussed in Section 5.3.1).

4.3.3 Propulsion

The BAA 94-2 contract awards included $5.4 million to P&W, and $3.7 million to General Electric teamed with Allison, for various propulsion technology demonstrations. To maximize the cost effectiveness of the demonstrations, several of the projects used existing test engines and leveraged ongoing programs, such as Integrated High Performance Turbine Engine Technology (IHPTET), Component and Engine Structural Assessment Research (CAESAR), Component Improvement Program (CIP), and F119 and F414 development programs.[38]

In keeping with the earlier JAST Concept Exploration findings that indicated a high payoff for engine diagnostics Tech Mat, P&W conducted an Advanced Engine Diagnostics & Health Monitoring project. This included demonstrations of advanced life algorithms, component health assessment, acoustic foreign object damage (FOD) detection, and electrostatic engine monitoring system (EEMS). (Following the completion of these efforts, advanced engine diagnostics work has continued under the JSF Prognostics & Health Management (PHM) initiative). P&W also conducted a fan duct heat exchanger demonstration that supports the J/IST Program, and a low observable axisymmetric nozzle (LOAN) demonstration on an advanced F119 test engine.

General Electric also demonstrated a low observable axisymmetric nozzle, piggybacking the tests onto an ongoing F110 Component Improvement Program test (Figure 35). This project included static (non-flying) signature measurements of the nozzle mounted on an F-16 aircraft, and 500 hours of engine operation to test the durability of the LO coatings and seals. A neutral network project, Model Based Intelligent Digital Engine Control (MoBIDEC), was also conducted by GE to detect seeded faults. This work was also continued under PHM.

Figure 35: F-16 with GE F110 LO Axisymmetric Nozzle

While these projects were underway, however, the Propulsion IPT's mission changed considerably. By this time, the overall JAST Program focus had shifted to the concept of a tri-service family of aircraft, with STOVL, CTOL, and CV variants. Successful demonstration of this concept would require careful attention to the development of adequate propulsion systems. The primary emphasis in the propulsion area therefore moved from generic Tech Mat, to propulsion system development in support of each prime contractor/team's tri-service weapons system concept. The Propulsion IPT became a separate Program Management team within the JSF Program Office by mid-1996, led by [redacted] from NAVAIR, with Lt Col [redacted] USAF, as deputy (he had replaced CDR [redacted] in June 1995). Major CDDR propulsion events are therefore described under Weapon System Concept Development, in Section 4.4.3.

While no longer the primary emphasis, several propulsion Tech Mat efforts continued, and are in fact critical to achieving the thrust levels, weight, cost, reliability, and durability required for a JSF engine. Because the three WSCs selected derivatives of the F119 engine in the spring of 1995 to power their weapon system concepts, it has been possible to focus propulsion investments on the transition of advanced technologies specifically into the F119 engine. Some of the efforts are WSC-unique, while others are for both WSCs. Because the F-22 also uses the F119 engine, there has been considerable opportunity to cooperate with the F-22 program and to leverage F119 technology improvements for both programs. JAST/JSF has also continued to leverage IHPTET and other laboratory programs.

For example, JAST/JSF invested in demonstrations of neural network-based engine prognostic systems, advanced thermally stable fuel (for improved ability to use the fuel as a heat sink), and the IHPTET Superblade/Supervane concepts. Superblade and Supervane feature enhanced cooling permitting higher thrust through higher operating temperatures, or improved durability at any given thrust level. Superblade and Supervane were not included in the F-22's baseline F119 engine configuration, but have been identified by the F-22 Program Office as technologies that could be introduced as future upgrades or to resolve shortfalls. The F-22 Program has therefore shared with JSF the cost of additional testing to mature the Superblade and Supervane technologies.

4.4 Weapon System Concept Development

The JAST Concept Exploration studies and related activities led to the conclusion that a highly common, tri-service family of strike aircraft was potentially feasible, and would achieve significant savings compared to the cost of developing and producing two or three completely distinct aircraft. This conclusion shifted the focus of the JAST Program from "generic" technology and requirements "building blocks," towards a specific weapons system. Rather than "spinning off" a variety of development programs starting in the year 2000, it became more likely that JAST would *become* a weapons system development program. The Concept Definition & Design Research phase accordingly focused on developing and refining the strike weapons system concepts in accordance with the "family of aircraft" approach, and defining the necessary leveraging technology demonstrations to reduce risk prior to entering EMD.

Through JAST BAA 94-2, contracts were awarded to Boeing, Lockheed Martin, McDonnell Douglas (teamed with British Aerospace), and Northrop Grumman, for Concept Definition & Design Research (CDDR) efforts. The contracts ranged from approximately $20 million to $28 million in value (as previously listed in Table 3), and covered a 15-month period from December 1994 through February 1996 (they were later extended through January 1997 to cover the duration of the CDP source selection and contract negotiations). Upon contract award, Northrop Grumman executed an agreement with McDonnell Douglas/British Aerospace, forming a single team for the JAST CDDR and (if successful) subsequent phases. This was formally announced at the CDDR kick-off review in January 1995. Although both contracts remained in effect, they were managed as one under a single statement of work (SOW). A Lockheed-Boeing teaming agreement was rumored, but never materialized.

The JAST CDDR contracts had the following fundamental objectives:

- Identification of joint strike aircraft design characteristics and integrated weapon system concepts to meet warfighter needs and contribute to significantly reduced cost of joint strike warfare
- Identification of support and training concepts that contribute to lower LCC, enhanced supportability, commonality, and deployability
- Definition of a comprehensive plan for an aircraft demonstrator and associated ground demonstrations

In support of these objectives, the WSCs performed tasks related to the following accomplishments:

1. Identification of significant risk areas and preparation of proposed risk mitigation plans.
2. Assistance to the warfighters in establishing balanced and affordable operational requirements, through cost/performance trade-offs using JPO-approved simulation models, metrics, and scenarios.
3. Analysis to demonstrate how their concepts contribute to reduced LCC.
4. Systems engineering and systems integration applicable to each weapon system concept.
5. Execution of associate contractor agreements with the Tech Mat contractors, to facilitate integration of advanced technologies for affordability into their PWSCs.
6. Propulsion system integration, including tasks necessary to define a complete preferred propulsion system and definition of a recommended risk reduction path.
7. Avionics system integration to include definition of allocated functional performance requirements; integration of apertures; definition of avionics budgets for weight, volume, power and cooling; and life cycle cost-performance trade-off analyses.
8. Weapons integration to include identification of alternative approaches to achieve lower LCC for carriage and integration of existing and projected weapons and other stores while maintaining acceptable RF signature levels and aerodynamic performance. Identification of technologies/processes/tools to reduce cost for weapons integration.

9. Identification of concepts and technologies that contribute to reduced aircraft weapons system operations & support (O&S) costs, and reduced cost for development, acquisition, and support associated with support and training systems.
10. Identification of appropriate flying concept demonstrator aircraft with focus on identifying key/critical technical and/or design issues, and reduction of technical risk associated with transition into development.

The CDP, following the CDDR phase, was intended to accomplish all necessary pre-EMD risk reduction, without incurring the cost of building and flying highly representative prototype aircraft. Accordingly, the contractors were instructed (in Task #10 above) to include in the flying concept demonstrator aircraft only those technologies or design features that required flight demonstration for risk reduction. Simulation, analysis, and/or ground demonstration were to be used extensively, together with the Concept Demonstration flight test results, in validating each contractor's concept. This led to the development of two parallel design efforts:

- The Concept Demonstrator Aircraft (CDA) represent the aircraft—in as many variants as necessary—that each contractor intended to build and fly in approximately the year 2000 as part of CDP. These would be low cost demonstrator aircraft, using existing off-the-shelf components where possible and would have no mission avionics or stealth treatments.
- The Preferred Weapon System Concept (PWSC) represents each contractor's intended family of production JSF aircraft, including all service variants as envisioned at IOC around the year 2010.

As described previously, during the JAST Concept Exploration phase the prime contractors had considered a broad range of aircraft designs, including the concepts that were being developed in the DARPA ASTOVL Program, along with concepts that were completely unrelated to ASTOVL. The incorporation of the ASTOVL Program into JAST occurred at approximately the beginning of the CDDR Phase. By this time JAST was focused on a tri-service family of strike aircraft, with a STOVL variant for the USMC (joined by the UK RN), a CTOL variant for the USAF, and a CV variant for the USN. The ASTOVL design efforts became synonymous with the JAST weapon system concept design efforts at that time. The configurations evolved considerably, however, to accommodate the different priorities and focus of JAST.

In the ASTOVL Common Affordable Lightweight Fighter (CALF) Program, the contractors' concepts were based on a set of Design Guidelines with only two hard "requirements": [*]

- Empty weight of the operational aircraft not to exceed 24,000 lb.
- Spot Factor (a measure of carrier deck parking space) not to exceed that of an F/A-18C.

Two variants were envisioned: the STOVL variant, and a CTOL variant for the U.S. Air Force, in which the powered-lift equipment would be replaced by additional internal volume for fuel and/or armament.

JAST, on the other hand, initially focused on a two-variant Navy/Air Force family, although a Marine Corps AV-8B and F/A-18C/D replacement became part of the plan very early in the program, well before ASTOVL was absorbed. The tri-variant family would be a lot more technically challenging than either a USMC-USAF or a USN-USAF bi-service family.[39] In addition, JAST was developing operational requirements in parallel with advanced technologies and concepts. The primary impacts of combining the two programs were as follows:

- The contractors had to develop carrier-suitable Navy variants, i.e., capable of catapult takeoffs and arrested landings, including suitable low-speed flying qualities for carrier landing approaches.

[*] The term "requirements" is used in this context to mean a "hard" limit, as opposed to a flexible goal. This is not to be confused with a formal military requirement, since ASTOVL did not have a formal requirements document, and JAST was only beginning to develop its initial requirements documentation.

While some of the ASTOVL contractors had begun to consider carrier suitability even before October 1994, this had a significant influence on the development of all contractors' designs after the programs were merged.

- The contractors had to consider other evolving operational requirements—including supportability—earlier than they would have in the ASTOVL program.
- At the same time, the allowable design space was expanded somewhat, because JAST did not retain the ASTOVL program's original "hard limits" on spot factor and empty aircraft weight. This gave the contractors flexibility to evolve slightly larger, heavier aircraft as necessary to accommodate three services' requirements, subject to the following limitations:
  - Available vertical thrust in hover (as opposed to a government-specified limit on aircraft empty weight).
  - Elevator size on UK aircraft carriers. The elevators are located in the middle of the ships' flight decks, so there is no room for overhang. While this is slightly different from the U.S. Navy's "spot factor" definition, it does impose a hard limit on aircraft planform dimensions (in the wings-folded configuration, if applicable).

Descriptions of each contractor's design concepts can be found in Chapter 6.

4.4.1 Analysis and Testing During CDDR

All contractors conducted detailed engineering analysis of their evolving configurations during the CDDR phase. Electronic mockups were used to evaluate manufacturing and maintenance concepts. Piloted simulations were conducted to evaluate STOVL and wing-borne flight characteristics. Cockpit layouts, avionics suites, vehicle management and propulsion control systems, and maintenance information systems were defined. Aerodynamic, structural and signature characteristics were analyzed using computational techniques and extensive scale model testing.

Each of the three contractor/teams accumulated several thousand hours of test time during CDDR. Including the full-configuration SSPM and LSPM tests described above, other powered lift testing, wind tunnel tests of wing-borne aerodynamics, stability & control, and engine inlet performance were accomplished. Each contractor also built radar cross section (RCS) models, and took radar range measurements to verify signature characteristics of their designs.[40]

The WSCs participated in many of the JAST Tech Mat demonstration efforts during CDDR. Depending upon specific technologies, some Tech Mat projects were awarded to the WSCs (in some cases with specialized vendors as subcontractors), while others were awarded to the subsystems developers (examples in Section 4.3). In all cases, ACAs or similar means were used to assure that all data and results were made available to all of the WSCs. This arrangement, while very unusual in a highly competitive program, was chosen as the best way to facilitate the transition of the technologies into the contractors' weapon system concepts.

However, the WSCs were not directed to incorporate any specific technologies. Rather, the technology needs they identified were used as a "filter" in selecting JAST Tech Mat investments. In some cases, the WSCs subsequently incorporated the technologies or concepts demonstrated—a situation that often led to a subcontractor arrangement for the ongoing WSC effort. In cases where demonstrations indicated that technology was not ready or unable to fulfill expectations, further expenditure of funds was cancelled. In essence, the prime contractors adjusted their limited funding profiles to complement or deconflict with the Tech Mat efforts. Thus, the interaction between the TM IPTs and the WSCs was both two-way and mutually beneficial.[41, 42]

4.4.2 Final CDDR Deliverables

Two principal deliverables were provided upon completion of the prime contractors' CDDR efforts:

- A Comprehensive Concept Development Plan for the recommended weapon system, describing design features, characteristics, and proposed operational, manufacturing, and support concepts
- A demonstration plan addressing ground and flight demonstrations considered necessary for low-risk transition of technologies into EMD. The plans addressed CDA requirements and demonstration objectives, additional concept specific ground and flight demonstrations, and generic Tech Mat demonstrations.

From these plans, the following critical demonstration objectives for all contractors' CDA emerged:

- Commonality/modularity among variants
- STOVL hover and transition
- Low speed flying and handling qualities suitable for carrier operations (Navy variant)

These became the key CDA flight demonstration objectives for the next phase of the program.

4.4.3 Propulsion System Development

The Propulsion IPT was initially part of the JAST TM Directorate and was expected to focus on Tech Mat issues through component demonstrations and a ground engine demonstration. JAST flight demonstrations were to use existing, off-the-shelf engines, and could therefore proceed independently of propulsion Tech Mat.

However, as the overall JAST focus converged on a tri-service family of aircraft, two key propulsion system features became critically important:

- Sufficient reliability for single-engine Navy variant
- Sufficient non-afterburning thrust for STOVL operations

In response to the first issue, several Tech Mat projects focusing on reliability and advanced engine diagnostics were initiated. However, the reliability of a propulsion system is very much a function of the maturity of the system and the adequacy of testing and analysis that is performed during development. The second key issue—thrust—would have to be addressed largely through concept-specific development based on an existing engine. The P&W F119 and the GE YF120 engines, both originally developed for the USAF Advanced Tactical Fighter program, were identified as the only existing engines from which a common JAST propulsion system could be derived.

In the spring of 1995, all three WSCs selected derivatives of the F119-PW-100 to power their JSF concepts. All designs utilized the F-22's F119 engine core, with the nozzle, fan, controls, and other features tailored to individual aircraft requirements. The Boeing and Lockheed Martin configurations each would require new fan and low pressure turbine (LPT) designs, based on existing F119 materials, aerodynamics and manufacturing technology. The new low spool designs—although different for the Lockheed vs. the Boeing concepts—would be common among the variants of each concept. The MDA/NGC/BAe aircraft design utilized the existing F119 for its main engine, plus a new (unidentified) lift engine. All three concepts required new nozzles. Whichever concepts were selected for the flight demonstration, propulsion system development would be critical to the successful demonstration of STOVL capability.

All of these considerations led to a shift in emphasis for the JAST propulsion team. Managing the development of specific propulsion systems, to meet the needs of evolving tri-service aircraft family design concepts, became the central priority. The JAST Propulsion IPT was reorganized accordingly. As previously mentioned, by mid-1996, a separate Propulsion Program Management Team was formed to be led by (b)(6) [redacted] USN, former F414 Program Manager.

There was, during the same period, a corresponding shift in the propulsion acquisition strategy for CDP. In the original plan, off-the-shelf engines for CDP would be Contractor Furnished Equipment (CFE), meaning that the prime (airframe) contractor would procure and integrate the engine(s). When it became apparent that propulsion system development was required, the strategy shifted towards Government Furnished Equipment (GFE) to maintain stronger management control over engine development, which was critical to the success of the program.

As noted previously, a Synergistic Demonstrator Engine (SDE) effort was briefly considered during mid-1995, to develop a single propulsion system for both the Lockheed and Boeing CDA. This idea was rejected primarily because of the significant differences between the two companies' concepts, and also because it could only meet the needs of two out of the three WSCs in the program at that time. When full funding for flight demonstration of two competing concepts, including the necessary propulsion system development, was approved in late 1995, the SDE and similar options became unnecessary.

The SDE would have had to be GFE, because it would have been developed for two competing WSCs. After this plan was abandoned, it was decided that the cruise propulsion systems would be GFE, and the powered lift components would be CFE. Other advantages of this arrangement were better continuity and simpler contracting arrangements for P&W, who also provides the F119 engine as GFE for the USAF F-22 aircraft. With the JSF cruise propulsion systems also GFE, P&W would not manage to have two separate F119 efforts. This would result in significant cost savings.

Contract negotiations with P&W were initiated to support propulsion system design for the JAST WSCs. However, selection of the same engine for the F-22 and all potential JSF designs prompted concerns about lack of competition, and excessive reliance on a single engine supplier for a large portion of all future U.S. tactical aircraft. During the summer of 1995, Congress directed the JPO to also pursue an alternate engine source. Accordingly, two propulsion contracts were awarded in November 1995:

- **Pratt & Whitney:** $30 million to carry out Propulsion Preliminary Design of derivatives of the F119 engine for all three WSCs. This 11-month effort (later extended) also included refining engine performance computer models (decks) and ordering long-lead hardware for the initial test engines.
- **General Electric/Allison:** $7 million for Alternate Engine Program (AEP) Phase I, to investigate "best fits" and begin preliminary design work for each WSC with derivatives of both the F110 and YF120 engines.

An engine reliability study by Johns Hopkins University/Applied Physics Laboratory (JHU/APL) was begun in September 1995. This was a follow-on to the earlier 1 vs. 2 engine studies, and was part of the continuing effort to ensure the acceptability of a single-engine aircraft by the Navy. The purpose of this reliability study was to identify the primary causes of engine failures, based on existing historical data; this assisted the JSFPO in determining the best leveraging technologies for improved engine reliability for the next phase. The final report was delivered in April 1996.

A sole source RFP was issued to P&W in April 1996 for the JSF CDA propulsion systems. Following the submission and evaluation of the proposal, and contract negotiations, a contract was awarded to P&W in January 1997 with a total value of over $800 million. By that time, Boeing and Lockheed Martin had been selected as the two WSCs who would continue into the CDP. P&W's contract therefore covered the following:

- Design, development and flight qualification of the F119 variants
- Delivery of flight test engines, and flight test support, for the Boeing and the Lockheed Martin JSF Concept Demonstrator Aircraft
- Continued refinement of the PWSC propulsion system designs
- Some Tech Mat work (primarily in the areas of cost and weight reduction, low observables, and engine diagnostics) applicable to both concepts

The F119 variants for Boeing and Lockheed Martin were designated SE 614 and SE 611, respectively.

4.4.4 Alternate Engine Program (AEP)

As noted above, the GE/Allison AEP was begun in response to Congressional direction in the summer of 1995. The Phase I contract of $7 million was awarded to GE in November 1995 to assess the suitability of derivatives of two candidate GE engines—the F110 and the YF120—for all variants of each prime contractor's PWSC. (The F110 was developed during the 1980s, as an alternate engine to the P&W F100 for the F-16.)

In early 1996, the YF120 was identified as the "best fit" for all WSCs as described below:

> General Electric worked with the WSCs to evaluate the F120 and F110 engines for each of their PWSC aircraft. The study showed that only the F120 has enough core horsepower to meet tri-service requirements and provide potential for growth. The F110 cannot meet the Marine STOVL requirement and will need a significant technology infusion with a commensurate increase in development cost to meet either the USAF or Navy requirements. The F120 will provide a highly flexible and robust platform from which an Alternate Engine can be developed….[43]

This decision completed what became known as Phase IA of the AEP, selection of the "best fit" engine. Phase IB concentrated on the conceptual design of an alternate engine configuration for each WSC, based on a common core (designated the YF120-FX) with concept-specific low pressure components.

In March 1996, Rolls-Royce joined the GE/Allison AEP team. In April 1996, a sole-source RFP was issued for Phase II. Phase I was completed with a Final Review on 6 November 1996, and the Phase II Kick-Off was held the following day, although final contract negotiations were still underway; work proceeded under an extension of the Phase I contract. The Phase II contract, worth $96 million from FY97 through FY00, was finally awarded in February 1997.

Phase II will concentrate on the development and testing of a common alternate engine core that will be applicable to either JSF weapons system concept. By concentrating on core development during the JSF CDP phase, the cost of concept-unique, low-spool development for the non-selected WSC will be avoided. After the JSF EMD downselect, Phase III from 2001 to 2004 will mate the appropriate low pressure system to this common core. Then, EMD of the alternate engine is expected to begin. Based on the plans at the time, the first production JSF alternate engines were expected to be available for use in JSF aircraft production Lot 5. With the funding available, however, the GE engine will not be ready until Lot 7, with the first deliveries in 2013. This acquisition strategy provides for competition between F119 and F120 variants for production Lot 7 and all subsequent production lots of JSF aircraft.

The AEP is expected to provide the following benefits that have historically resulted from engine competitions in past programs:

- Reduced acquisition cost
- Reduced risk
- Improved engines
- Better warranties and product support

The phased approach (as opposed to simultaneous development of two JSF engines) will still provide the alternate engine very early in the JSF production phase. About 10% of the anticipated total production of JSF engines is expected to be procured prior to the introduction of the alternate engine.[44]

4.5 Transition to CDP

4.5.1 CDP Source Selection

The first planning meeting for the CDP source selection was held during June 1995. Ideas for reform and streamlining, gathered by the Acquisition Reform Focus Team, were considered in planning the CDP source selection. The Acquisition Reform Focus Team provided the primary forum for interaction with the WSCs to identify opportunities for streamlining, for the CDP source selection as well as all other aspects of the program.

The CDP source selection was different from previous JAST/JSF source selections in several ways. For the first time since the program began, the Source Selection Authority (SSA) was outside the JPO. In this case, because the Air Force had oversight responsibility for the program (after RADM Steidle became Program Director), the SSA was the Secretary of the Air Force, Dr. Sheila Widnall. RADM Steidle headed the source selection team, and Mr. Patrick McLaughlin was Principal Contracting Officer.

Because this procurement was related to the development of a specific weapons system, a formal RFP had to be used, rather than the more streamlined BAAs used in prior JAST solicitations. However, every effort was made to keep the RFP and the proposals as concise as possible. The philosophy was to give the contractors maximum opportunity to apply their own ideas to achieve cost savings. Toward this end, the JPO did not include a detailed SOW in the RFP, as is often done, but only a broad Statement of Objectives (SOO). Each contractor would then propose their own SOW containing essential tasks to achieve those objectives. In July 1995, an initial draft SOO was released to industry.

Appropriate page limits for each section of the proposals were determined through discussions with the contractors. The total proposals were limited to 569 pages plus up to 200 pages of supporting data, 15 drawings, and one propulsion data tape. For comparison, the earlier A/F-X program had allowed up to 2,675 pages, plus unlimited supporting technical data, for its Demonstration/Validation phase proposals.

To accomplish the source selection in this manner required a fundamental change in evaluation philosophy. There would not be room for the usual amount of technical data in the proposals, which evaluators normally use to make their own independent estimates of the performance, cost, and other characteristics of the proposed weapon systems. Instead, the evaluators would have to look over the contractor estimates, and if the methodology and assumptions appeared reasonable, accept the contractors' results.[45]

Development of the detailed source selection strategy, and the RFP itself, proceeded through the summer of 1995. In August and September, program reviews to the JROC, the USD(A&T), and the DAB resulted in approval to initiate the procurement process. A Sources Sought Synopsis was published in the CBD on 3 November 1995. A draft RFP was approved by the DAB on 14 December and released to industry on 18 December. Industry responses to the first draft were received on 12 January, and a revised draft RFP was released on 22 January 1996. The final pre-solicitation conference with the offerors was held on 21 February 1996. At this meeting, the evaluation standards to be used in the source selection were provided to the offerors. Throughout the whole process—before, during, and after the source selection—the JPO shared an unprecedented amount of information with the WSCs. This was intended to allow each contractor to develop the best possible proposal, to make the evaluation as fair as possible, and to avoid any misunderstandings that could lead to a protest.

While the value of the weapons system Concept Definition & Design Research contracts in the previous phase ranged from $20 to $28 million each, and the largest Tech Mat contracts were on the order of $50 million, the CDP contracts would be worth close to $1 *billion* each, not to mention the importance of staying in the competition for EMD and production. The outcome of the CDP source selection could therefore have a significant impact on the future of the companies involved. A protest could be disastrous to the program,

so extreme care was taken to insure a fair and thorough evaluation with no compromises to the integrity of the process.

Approximately one third of the JPO office space was partitioned and transformed into a source selection facility. Access was limited to those personnel directly involved in the source selection. WSC personnel were not permitted in any part of the JPO after the final pre-solicitation conference in February. Only specific program personnel were authorized to communicate with the WSCs. Other than those discussions that were part of the source selection process, such communication was restricted to the minimum necessary to conduct the ongoing Tech Mat and requirements efforts. (The Requirements Directorate did not participate in the source selection, so that they could continue their work with the WSCs on cost/performance trades.)

The final RFP was reviewed by the SSA on 4 March 1996, by the USD(A&T) on 7 March 1996, and released to industry on 22 March 1996. Proposals were submitted by the contractors (on CD-ROM) on Friday, 14 June, and were entered into the evaluation network computers over the weekend of 15-16 June. Evaluation began on 17 June.

As usual, the source selection was accomplished electronically. (The electronic source selection process is described in greater detail in Section 8.2.2.) Some tasks, however, still required paper, particularly with regard to the technical evaluation. For example, it is very difficult to get useful information from graphs displayed on a computer screen, especially when they have been scanned and pasted into the proposal files at a reduced scale to stay within the proposal page limits. In many cases graphs were printed out, enlarged, and then digitized to place the data in a useful format. In the future, allowances should be made for submitting graphical data on paper at a useful scale; alternatively, to keep the evaluation electronic, data could be presented in tabular form rather than as graphs.

Face-to-face discussions with the WSCs were held in late August and early September, and Best And Final Offers (BAFOs) were requested on 9 September. The BAFOs were received on 19 September and evaluated between 19 September and 18 October. Meetings and briefings with the Source Selection Evaluation Board (SSEB), Source Selection Advisory Council (SSAC), the SSA, and other appropriate officials, were held during the remainder of October and early November. Concurrently, final Milestone I briefings and reviews were conducted (as described in the following section), leading to a Milestone I approval on 15 November. Announcement of the CDP source selection decision was made on Saturday, 16 November 1996, by the Secretary of Defense in a televised press conference.

The Boeing Company and Lockheed Martin Corporation were selected to continue into the CDP. The two companies were awarded contracts of $661.8 million and $718.8 million, respectively. The contract amounts were determined by allocating approximately $1.1 billion to all work by or in support of each competing WSC, including STOVL and cruise propulsion system effort. However, because the CDA cruise engines were defined as GFE, that portion of the work was not awarded to the two WSCs, but rather to P&W. The prime contract values therefore represent approximately $1.1 billion each, less the GFE propulsion work for each competing concept. GFE propulsion work in support of Boeing and Lockheed Martin, and a small amount of Tech Mat, were rolled up into a single P&W contract of $861.4 million as illustrated below. (Because STOVL-specific propulsion components were generally defined to be CFE, these are being developed under a variety of subcontracting arrangements and are not broken out in Figure 36.)[46]

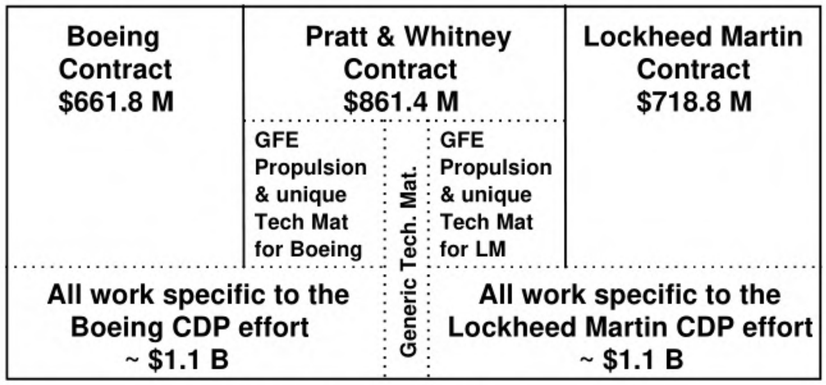

Figure 36: Initial CDP Contract Values

The CDP proposal evaluation was extremely thorough and very well documented. Following the announcement of the decision, all of the offerors were provided with detailed debriefings. The offerors commented favorably on the quality of the debriefs, and the unsuccessful offeror immediately announced that they did not intend to protest the decision. The successful accomplishment of this major source selection without protest, while implementing a number of acquisition reform and streamlining initiatives, was a primary reason for the presentation of two major acquisition awards to the JPO: the USAF Acquisition Lightning Bolt Award and the DoD David Packard Excellence in Acquisition Award, both presented in March 1997. The full citations accompanying these awards appear in Appendix B. A chronology of the entire source selection process is presented in Table 10.[47]

Table 10: CDP Source Selection Events and Dates

Event	Date
Initial RFP planning meeting	Jun 95
Draft Statement of Objectives (SOO) to industry	21 Jul
Program reviews: JROC Review of program and JIRD I requirements Overarching IPT (OIPT) Program Overview USD(A&T) Review of program and contractors' concepts Defense Acquisition Board (DAB) CDP Review	3 Aug 16 Aug 22-23 Aug 5 & 9 Sep
Sources Sought Synopsis in Commerce Business Daily (CBD)	3 Nov
Draft RFP Reviews: OIPT DAB	11 Dec 14 Dec
First Draft RFP release	18 Dec
Secretary of the Navy review of program, acquisition strategy, and concepts	10 Jan 96
Industry responses to Draft RFP	12 Jan
Acquisition Strategy Panel working session	17 Jan
Revised Draft RFP release	22 Jan
Issue Synopsis	15 Feb
Pre-solicitation Conference / Evaluation Standards provided to contractors	21 Feb
Final RFP Reviews: Secretary of the Air Force USD(A&T)	4 Mar 7 Mar
Final RFP release	22 Mar
Acquisition Strategy briefing to Source Selection Advisory Council (SSAC)	2 May
JSF designated an ACAT I D major defense acquisition program	23 May
Proposals received	14 Jun
Evaluation begins	17 Jun
Early Clarification Requests / Deficiency Reports (CRs/DRs) to contractors	17 Jul
Source Selection Evaluation Board (SSEB) meetings	29 Jul to 1 Aug
Competitive Range brief to SSAC, and CRs/DRs issued	16 Aug
Face-to-face discussions with contractors	20-22 Aug, 26-30 Aug, & 3-5 Sep
Assistant Secretary of the Air Force (Acquisition) (SAF/AQ) update	22 Aug
SAF/AQ update and Best and Final Offer (BAFO) request	9 Sep
BAFOs received	19 Sep
Evaluate BAFOs	19 Sep to 18 Oct
SSEB meetings	21-25 Oct
Briefings to SSAC	30-31 Oct
Briefing to Source Selection Authority (SSA)	5 Nov
Briefing to SSA; SSA selects sources; USD(A&T) approves Milestone I	Fri 15 Nov
Results announced and contracts awarded	Sat 16 Nov

4.5.2 Corporate Aftermath

Less than a year after the decision, each member of the unsuccessful McDonnell Douglas/Northrop Grumman/British Aerospace team had merged and/or teamed with one of the successful WSCs. On 15 December 1996, Boeing announced plans to merge with McDonnell Douglas Corporation. In June 1997, British Aerospace announced that it would team with Lockheed Martin. On 1 July 1997, the Federal Trade Commission approved the Boeing/McDonnell Douglas merger, and two days later Lockheed Martin

announced plans to merge with Northrop Grumman, and to bring Northrop Grumman onto their JSF team. In early 1998, however, the U.S. Justice Department indicated that it would block the merger. In July 1998, Lockheed Martin announced that it would not fight the lawsuit, but would continue its JSF teaming with Northrop Grumman. Excerpts from the announcement are given below:

> Our decision is based on several factors, including the inability to structure an agreement that would address all the government's concerns and allow the transaction to proceed without protracted litigation with our principal customer, the U.S. Department of Defense. We also recognize that a lengthy trial would have created a distraction for many of our employees, particularly in those businesses where facility consolidations might occur had the two corporations combined. Termination of the merger agreement eliminates this uncertainty, enables us to devote our full attention to customer satisfaction, and permits Lockheed Martin to pursue other strategic opportunities that will grow shareholder value and enhance competitiveness in the global marketplace….
>
> We certainly are disappointed that the merger with Northrop Grumman will not occur, but have come away from our close association with the company and its people over the last year thoroughly impressed by their capabilities, technologies, and focus on service and value. We fully intend to continue our strong relationships with Northrop Grumman as team members, customers, and suppliers.[48]

4.5.3 Milestone I Preparations

As noted previously (in Section 4.1.8), JSF became an ACAT I D program in May 1996, and therefore became subject to the established system of milestone reviews for acquisition programs. When that decision was made, the formal RFP for the planned CDP—analogous to Phase I (Program Definition & Risk Reduction) of a formal acquisition program—had already been released. An Acquisition Decision Memorandum (ADM) signed by the Milestone Decision Authority (in this case the USD[A&T]) was required before JSF could enter CDP.

The Overarching IPT (OIPT) lead,* Dr. George R. Schneiter, Director for Strategic & Tactical Systems, Office of the Under Secretary of Defense (Acquisition &Technology) (OUSD[A&T]), and [redacted] JSF Program Integration Director (later JSF Program Technical Director), and their supporting staffs worked out a preliminary strategy that would satisfy all statutory requirements and meet OSD objectives, while providing minimum disruption to the program in light of the ongoing source selection. It was recognized that most of the requirements for program oversight and review had, in substance, been satisfied during the series of DAB-like reviews held from August 1995 through February 1996. What remained, primarily, was to formally document the plans and approaches that had been approved during those reviews. The documentation was consolidated in the Single Acquisition Management Plan (SAMP).

Lt Col [redacted] a member of the JSF Program Integration Directorate and Program Manager for the Lockheed Martin CDDR contract, was placed in charge of SAMP development. A highly streamlined approach was taken: rather than starting with the standard set of Milestone I documentation and "tailoring out" specific items, the approach was to start with a "clean sheet of paper" and *tailor in* only essential elements. The guiding principles were:

- Don't create anything new—just document what was decided earlier.
- Do what's required by law.
- Justify anything else for inclusion in the SAMP.

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* Major DoD acquisition programs have essentially two levels of Integrated Product Teams (IPTs) above/outside the program office. The highest level is the Overarching IPT (OIPT), headed in the case of non-space weapon systems by the Director of Strategic & Tactical Systems in OUSD(A&T). The OIPT provides strategic guidance through the acquisition life cycle of a program, and makes recommendations to the Milestone Decision Authority. Below this, one or more Working Level IPTs provide guidance to the Program Manager, early input on acquisition review documents, and coordination with the OIPT. In programs with more than one Working Level IPT, an Integrating IPT (IIPT) is required. The IIPT for JSF was co-chaired at that time by Mr. Fred Schwartz, JSF Program Integration Director, and Mr. Ron Mutzelberg from the Office of the Director of Strategic & Tactical Systems in OSD.

With support from personnel at the ASC JSF Support Office, Wright-Patterson AFB, a spreadsheet was developed listing every Milestone I documentation requirement contained in the DoD 5000 series of acquisition policies. The 100-page spreadsheet included the item required, and the applicable portion of the statute or regulation where the reference was found. This process helped to identify what had to be included in the SAMP, and what did not.

In June, the basic plan was presented to Dr. Schneiter and his staff, who tentatively agreed that the following elements would be sufficient for the Milestone I approval:

- SAMP containing
  - Acquisition Strategy—roadmap for program execution
  - Cost as an Independent Variable (CAIV) objectives—how JSF would balance mission needs with out-year resources
  - CDP I Exit Criteria
  - Test and Evaluation Master Plan (TEMP) philosophy and approach
- Acquisition Program Baseline (APB) as an annex to the SAMP

Because of the ongoing CDP source selection, each contractor's specific weapon system design characteristics, cost data, test plans, and similar information was source selection sensitive, and by law could not be disclosed outside of the source selection process. The SAMP and the APB would therefore be based on the JIRD I and other "generic" program information. The SAMP, including the APB, would be completed by October, at which time the Overarching IPT (OIPT) would review the documentation. This would provide for a Milestone I decision in time for the planned CDP contract award in November. The approach was presented to, and approved by, [redacted] on 18 June.[49]

Lt Col [redacted] and other JSF program staff then met with members of the various OSD agencies to work the details. For example, JSF Manufacturing, Test & Evaluation, and Structures & Materials IPT Leads, respectively, met with the appropriate subject matter organizations in OSD to determine exactly what those agencies required to be in the SAMP.

The approach of "tailoring-in" was compatible with the acquisition reform philosophy advocated by OSD leadership and DoDD 5000.1. Nevertheless, some resistance was encountered along the way. The most difficult issues were:

- **TEMP:** This is normally included in the Milestone I documentation, but is not strictly *required* until Milestone II. There is no statute or regulation that requires a TEMP for Milestone I approval. Therefore, it was decided that the SAMP would not include a TEMP, but only a description of the planned TEMP approach.

- **CAIV:** The JSF Program was designated by USD(A&T) as a flagship program for the implementation of CAIV. CAIV was a relatively new initiative at the time and its meaning was ambiguous. Reconciling various differences, and coming to a consensus on what CAIV meant in the JSF Program, proved to be difficult. In fact, the JAST/JSF Program had been performing COPT studies, which are directly analogous to CAIV, long before the CAIV policy was formally articulated by DoD.

- **APB:** The APB initially contained only a minimum number of essential CDP flight demonstration goals, plus additional Desired Operational Characteristics. There was pressure, however, to include all of the JIRD I parameters in the APB, to identify Objectives and Thresholds, *and* to identify those requirements that were "Key Performance Parameters." Such premature commitment to specific quantitative requirements would have undermined the JSF approach to affordability, which is based on a continuous cost/performance trades throughout Phase I.

These issues and others were eventually resolved. However, the process required many iterations and much re-wording of program documentation. The JSF Program was chartered to explore new ideas to break

the historical trend of escalating real costs for fighter type aircraft, and has worked hard to do so. Nevertheless, there were organizations represented on the IIPT, which still saw their roles as directive in nature—i.e., oversight rather than teamwork—and opposed the JSF approach in various areas, including those mentioned above. However, when issues arose which could not be resolved at the working level, the acting SAE, Ms. Darlene Druyun, and Milestone Decision Authority, [redacted] were generally very supportive of the JSF Program's approach. They helped keep the program on track in accordance with the strategy that was approved during the series of DAB-like reviews in late 1995 and early 1996.[50]

4.5.4 Milestone I Decision

Following four Integrating IPT (IIPT) sessions and numerous side meetings with individual members from August through early October of 1996, the SAMP was completed to the satisfaction of the IIPT. The final version was released by the JPO on 11 October, and signed by the Air Force Service Acquisition Executive (AF SAE), Mr. Arthur A. Money, Assistant Secretary of the Air Force (Acquisition), on 21 October.

On 22 October, the Overarching IPT met to review the agreed-upon Milestone I documentation and to prepare a recommendation for USD(A&T). The recommendation was to approve entry into the CDP. The SAMP was subsequently signed by [redacted] OSD Director, Operational Test & Evaluation (DOT&E), on 23 October, and by Mr. John W. Douglass, ASN RDA, on 5 November. [redacted] signed the SAMP and an ADM on 15 November. The ADM, reproduced in Appendix B, constituted Milestone I approval for the JSF Program, and cleared the way for the CDP Contract Award, which was announced on 16 November 1996.[51, 52, 53]

4.6 Summary of Concept Definition & Design Research Phase

During the Concept Definition and Design Research Phase, the JAST/JSF Program accomplished the following major tasks:

- Absorbed the DARPA/UK ASTOVL (CALF) Program
- Advanced from general concepts for a tri-service strike weapons system, to specific designs, and selected two specific concepts which will be flight demonstrated in the CDP
- Established primary and alternate propulsion system development programs
- Conducted a number of Tech Mat demonstrations and built a robust, longer-term technology demonstration strategy based on the consensus of the S&T community, the WSCs' design teams, and the end users (warfighters and maintainers)
- Conducted extensive campaign-level modeling, simulation & analysis, released the JIRD I, and identified four "Requirements Pillars" which define the essential qualities of the JSF
  - Lethality
  - Survivability
  - Supportability
  - Affordability
- Secured full funding for the CDP, to include full-scale flight demonstration of STOVL, CTOL and CV variants of the two competing concepts plus key Tech Mat programs
- Became an international program
- Became an ACAT I D Major Defense Acquisition Program and negotiated a successful Milestone I decision

JSF was identified as a Flagship Program for the implementation of CAIV. Unit recurring flyaway (URF) cost goals and procurement quantities were established as shown in Table 11.

Table 11: Average URF Cost Targets and Planned Quantities at End of CDDR Phase

Variant	URF Target (FY94$)	Quantity	Service
CV	\$31–\$38 M	300	USN
CTOL	\$28 M	2036	USAF
STOVL	\$30–\$35 M	642	USMC
		60	UK RN
Total:		3038	

On 16 November 1996 the Boeing Company and Lockheed Martin Corporation were awarded contracts of \$661.8 million and \$718.8 million, respectively, for the CDP. This very challenging source selection was accomplished in a streamlined but thorough manner, and without protest from the unsuccessful offeror. P&W was also awarded a contract of \$869.3 million for CDP propulsion system development in January 1997, and GE received a contract worth \$96 million for Phase II of the JSF AEP in February 1997. The Milestone I decision memorandum was signed concurrently with the WSC source selection decision, thereby completing the Concept Definition & Design Research Phase and initiating the Concept Demonstration Phase of the JSF Program.

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5 Concept Demonstration Phase (CDP) Through 2000

The JSF Concept Demonstration Phase (CDP) began on 16 November 1996, with the award of weapons system prime contracts to The Boeing Company and the Lockheed Martin Corporation. CDP is scheduled for completion in late 2001, at which time a single prime contractor/team will be selected to proceed into EMD. CDP is Phase I of the JSF Program, corresponding to what is normally referred to in DoDI 5000.2 terminology as Program Definition and Risk Reduction (PDRR), formerly Demonstration/Validation (Dem/Val).

The major CDP objectives were as follows:

- The WSCs, Boeing and Lockheed Martin, are each to:
  - Build and flight test two CDAs to demonstrate:
    - Commonality/modularity among service variants.
    - STOVL hover and transition to/from forward flight.
    - Satisfactory low speed carrier approach flying and handling qualities.
  - Refine their PWSC designs.
  - Conduct additional concept-unique Tech Mat demonstrations.
- Engine development:
  - Pratt & Whitney is to develop, fabricate, test, and deliver flight test engines for the CDAs, provide flight test support, conduct common and WSC-unique Tech Mat demonstrations, and continue to refine their PWSC propulsion system designs.
  - General Electric is to accomplish Phase II of the Alternate Engine Program, focusing on the development of a YF120-derived core suitable for both competing JSF concepts.
- Requirements analysis, including:
  - Modeling, simulation & analysis, with increased emphasis on mission-level simulations and maintenance simulation.
  - Annual COPT studies and JIRD updates, culminating in a validated Joint ORD prior to EMD entry.
- Tech Mat programs have continued, culminating in several major demonstrations to bring selected technologies to low risk prior to EMD entry.
- Other necessary preparations to enter EMD, including:
  - Preparation and review of all required Milestone II documentation.
  - Source selection to a single weapons system prime contractor/team.

5.1 Program Management

Highlights of the first three years of CDP, related to program management, include the following:

- In March 1997, the JSF program received both the Air Force Acquisition Lightning Bolt Award and the David Packard Excellence in Acquisition Award.
- Brig Gen (later Maj Gen) Leslie F. Kenne, USAF, became JSF Program Director on 1 August 1997. In May 1999, the Deputy Director, Major General Michael A. Hough was promoted to the JSF Program Director. Brigadier General John (Jack) L. Hudson then became the Deputy Director.
- In addition to the UK, which had become a partner in 1995, Denmark, the Netherlands and Norway officially joined the Program in 1997; Canada and Italy in 1998; and Turkey, Singapore and Israel became participants in 1999. Also in 1999, the UK modified their participation to include replacement of the Royal Air Force's Harrier GR.7s. (International participation in the JSF Program is treated in detail in Chapter 9.) In 2001, the UK signed up to be a partner through EMD.

The JSF Program remains well supported, with stable funding. The Quadrennial Defense Review (QDR) conducted in early 1997 did not lead to any major changes to the program. The program is expected to be supported by the new Presidential administration that took office in January 2001. Additional program management activities during 1996-2000 are described below.

5.1.1 Program Office Reorganization for CDP

Starting in mid-1996, while the CDP source selection was in progress, the JPO began a reorganization to better meet the needs of the upcoming phase. By mid-1997, the new organizational structure was essentially in place. A JSF Program Office organizational chart depicting the structure as of late 1997 is shown in Figure 37.

As described in the previous chapter, the Propulsion IPT had already been moved out of the TM Directorate to become the Propulsion Program Management Team headed by [redacted]. Program management teams were also established to manage each of the selected WSCs' CDP efforts. Col [redacted] USAF (previously the Aeronautical Systems Center Liaison) became the Boeing X-32 Team Program Manager, while CAPT [redacted] USN (formerly Deputy Director, Program Integration & Analysis) became the Lockheed Martin X-35 Team Program Manager.

The TM Directorate was reorganized as the Systems Engineering (SE) Directorate. The role of the SE Directorate expanded to include technical and cost analysis in support of the WSCs' CDA and PWSC efforts, in addition to the existing Tech Mat responsibilities. Several new IPTs were either added or transferred from the Program Integration Directorate, as illustrated on the organizational chart below. Col [redacted] USMC (formerly the Program Integration Deputy for Technology Integration) became the Systems Engineering Director.

Mr. Fred Schwartz, SES USAF, previously the Director of Program Integration (PI), became the JSF Program Technical Director. A new Plans & Programs Directorate, under then-Lt Col Bruce Caughman, USAF, assumed responsibility for program integration and planning, and in particular, initial planning for the EMD phase. An International Programs Office (IPO) was established, initially headed by [redacted] (former DARPA ASTOVL Program Manager) and later by [redacted] (former Manufacturing & Producibility IPT Lead). The IPO was also later renamed the International Directorate.

[redacted] then assumed leadership of another new Directorate, initially called JSF Science & Technology, but later re-named Joint Advanced Strike Technology (resurrecting the original name of the JSF Program). While the Systems Engineering Directorate executed the technology strategy formulated primarily during the first two phases of the JAST Program, the JAST Directorate provided a continuing link to the S&T community, identifying projects that could transition to the JSF for EMD or subsequent upgrade. Through this mechanism, JSF may provide funding, advocacy, and/or act as a designated transition program for various S&T projects. The JAST Directorate was also the primary program link to NASA and DARPA, and coordinated use of government S&T assets such as NASA's test facilities.

In September 1997, another former TM IPT, Supportability & Training, was elevated and became the Supportability Directorate, headed by Col [redacted] USMC. This change was made to place increased emphasis and visibility in the area of weapons system sustainment and support.

In mid-1997, planning began to relocate the JPO from its overcrowded spaces in Crystal Square 4 and Crystal Gateway 1 to a new facility in the Crystal City area. In September 1998, the Program Office moved to Crystal Gateway 4, thereby co-locating all of the JPO staff and relieving the serious overcrowding.

(b)(6)

[redacted]

5.1.2 The Quadrennial Defense Review (QDR) and Related Issues

In January 1997, the Office of the Secretary of Defense initiated a Quadrennial Defense Review (QDR). Analogous to the Bottom-Up Review (BUR) four years previous, the QDR was intended to match overall U.S. military strategy to the pool of resources intended to accomplish it. The basic requirement was the same as in the BUR: maintaining the ability to win two near-simultaneous major regional conflicts (MRCs). However, there has been a great deal of debate and concern about how to fund the necessary levels of readiness, force structure, and modernization from the same, shrinking pool of defense dollars. Critics have suggested that there could be a "budgetary train wreck" waiting for the military's tactical aircraft programs, and that taken together, the JSF, F-22, and F/A-18E/F procurement programs may be unaffordable, given current program structures and limits on defense spending.[1]

The QDR studied alternatives to fighter modernization, including Unmanned Combat Air Vehicles (UCAVs) and the B-2 bomber. However, UCAVs cannot at this point replace fighters with humans in their cockpits, and the window of opportunity has passed for affordably restarting production of the B-2. Other alternatives were studied as well. The bottom line is that while other types of systems can fill certain needs, tactical aircraft are necessary, and current tactical aircraft must be replaced. For example, the average ages of the principal Air Force tactical aircraft in service today are illustrated in Table 12.

Table 12: Average Ages of Air Force Tactical Aircraft[2]

Aircraft Type	Active		Reserve		Guard		Total Force	
	Number	Average Age	Number	Average Age	Number	Average Age	Number	Average Age
A-10	223	14.8	51	16.0	101	15.8	375	15.2
F-16	806	6.2	73	8.8	631	10.0	1510	7.9
F-15	621	10.9	0	-	116	18.6	737	12.1

If these figures are projected to 2010, when the JSF is scheduled to achieve Initial Operational Capability (IOC), the average ages of A-10s and F-16s *now in the active inventory* will be 27 years and 18 years, respectively. The average age of the currently-active F-15s will be 17 years, when replacement by F-22s starts in 2004. The Navy (with the F-14 and F/A-18C/D) and Marine Corps (operating the F/A-18C/D and AV-8B) face similar aging aircraft situations. Aging aircraft are subject to corrosion and fatigue, while corrosion may, at least in theory, be prevented, fatigue cannot. Metal subjected to cyclic stress becomes brittle and cracks, causing damage that may be difficult to find, is often in the most critical areas, and is always expensive to repair. Routine operation of any aircraft results in cyclic stress, due not only to strenuous maneuvers, but also to gust loads, unsteady airflow (separated flow at high angles of attack, transient shock waves, etc.), engine noise and other acoustic sources. Frequencies range from one repetition per flight (landing loads) to several thousand cycles per minute (engine noise). These repeated cyclic stress loads eventually result in significant damage that cannot be prevented, and only corrected through expensive re-manufacturing programs.

For all of these reasons, the QDR, which was released in May 1997, had minimal impact on JSF Program planning, recommending only a slight reduction in U.S. JSF procurement from 2,978 to 2,852. The maximum production rate of 195 aircraft per year was not changed, but the year in which that rate will be reached was slipped from 2010 to 2012. The production buys were also adjusted between the services and for total numbers. The relatively small impact is not surprising, since the JSF itself is essentially a product of the BUR, which was based on the same two-MRC strategy. JSF is proceeding very close to the timeline originally envisioned by the BUR Report, with Tech Mat from 1995-2000, EMD start in 2001, and IOC in the 2010 timeframe. What made sense in 1993, still made sense in 1997. QDR recommendations

for the three tactical aircraft programs in question – JSF, F-22, and F/A-18E/F – are summarized in Table 13.[3]

Table 13: QDR Tactical Aircraft Procurement Recommendations[4]

Aircraft Type	Prior Plan	Post-QDR
USAF JSF	2036	1763
USN JSF	300	480
USMC JSF	642	609
Total JSF (US Only)	2,978	2,852
F-22	438	339
F/A-18E/F	1,000	548 to 785*

* Near the low end of the range if the JSF is introduced on schedule, or higher if JSF is delayed.

In 1997, the Air Force considered the procurement of two wings of STOVL-variant JSFs in addition to its planned CTOL buy. (A wing consists of 72 combat-coded aircraft, plus training and reserve planes, for a total of about 100 aircraft.) The Navy has also considered some STOVL variant JSFs. STOVL JSFs can be operated from smaller ships (in the case of the Navy) or based at forward, austere airstrips (in the case of the Air Force). However, there are other considerations such as competing budget priorities and service roles and missions. Neither service is currently planning to procure STOVL aircraft.

The cost of the JSF is of primary importance to all participating services. While second-best technology is perilous in aerial combat, the JSF simply must be affordable for the services to preserve adequate force structure. The length of time that the JSF will be in service also demands that the cost of ownership be firmly controlled. For these reasons, life cycle affordability remains the central focus of the JSF Program.

Historically, acquisition program costs have come under increasing scrutiny as programs progressed. In the case of the JSF Program, there have been some difficulties convincing service and OSD cost estimators of the validity of JSF Program cost estimates and the reality of the projected cost savings achievable through advanced technologies, affordable requirements and improved processes. Part of the problem is that the Cost Estimating Relationships (CERs) for military aircraft (originally developed by the RAND Corporation) are more than 20 years old, and do not provide any means to account for the savings opportunities identified by the JSF Program. While they have been adjusted, they have never been completely updated. RAND therefore, in conjunction with the WSCs (using their expenditures to date during CDP and their estimates at completion) and with inputs from the F-22 and F/A-18E/F EMD programs, updated the CERs to account for the new way of doing business. RAND specifically looked at advanced materials and processes, lean manufacturing and acquisition reform. RAND is current studying engine and avionics cost estimating processes. These updates should bring improved agreement between the JSF Program and the cost estimating community.[5,6]

5.1.3 Changes of Command

On 1 August 1997, Rear Admiral Craig E. Steidle left the JSF Program to become Vice Commander of Naval Air Systems Command (NAVAIR). He was replaced by Brigadier General Leslie F. Kenne, USAF, who had been the JSF Program Deputy Director since mid-1996. General Kenne was promoted to Major General in January 1998. General Kenne's top priorities, when she became Program Director, were as follows:

- To insure that the requirements process remained on track and focused on affordability, with the services working towards a family of strike weapon systems
- To execute CDP

- To establish a realistic plan, budget, and organization for EMD
- To place increased emphasis on supportability.[7]

In conjunction with the Program Director rotation, Service Acquisition Executive (SAE) responsibility shifted to the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN(RD&A)) Mr. John Douglass. Also in mid-1997, [redacted] retired from his position as Under Secretary of Defense (Acquisition & Technology). He was replaced by Mr. Jacques Gansler. In September 1997, Mr. Douglass requested a comprehensive review of the JSF Program. This review was performed by a joint service cost assessment team led by [redacted] of NAVAIR. Assistant Secretary Douglass stated that he was not so much concerned about the program, but simply wanted a status report so that he would be able to make informed decisions.[8]

In May 1999, Major General Kenne left the JSF Program to become the commander of Air Force Electronics Systems Center at Hanscom AFB, Massachusetts. Brigadier General Michael A. Hough, who had become the deputy in August 1997, was promoted to the JSF Program Director and received his second star. Brigadier General John (Jack) L. Hudson – previously the Senior Military Assistant to USD(A&T) Dr. Jacques Gansler – became the Deputy Director. The SAE shifted back to the Assistant Secretary of the Air Force for Acquisition, who was now [redacted] became ASN(RD&A) in October 1998 and continues to closely monitor the program.

In early 2001, with the change in Administration, a number of key positions in the JSF reporting structure were expected to be filled with new appointees.

5.1.4 Program Office Changes in Preparation for EMD

In preparation for EMD, a number of changes were made to the Program Office organization in late March 1999, as shown in Figure 38. An EMD Planning team was formed – with Col [redacted] as the director, and CAPT [redacted] as the deputy – planning for the transition from CDP to EMD, specifically preparing for the CFI release, source selection, DAB Milestone II decision, and EMD program structure. This personnel change opened the WSC Program Manager positions, allowing a simultaneous rotation of military personnel. This was done so as to be equitable to both WSCs, as well as only having to change once during CDP. It is planned that Col [redacted] USAF, will be the X-32 Program Manager and CAPT [redacted] USN, will be the X-35 Program Manager through EMD source selection. Col [redacted] USMC, became the director of Systems Engineering. The Supportability Requirements division was also absorbed into the Supportability Directorate, which was eventually renamed the Autonomic Logistics (AL) Directorate, under Col [redacted] USMC, and [redacted] the deputy. CAPT [redacted] became the AL Director in January 2000. The Airframe and Manufacturing IPTs also merged, with [redacted] previously the Airframe IPT Lead, leading the combined team. Finally, in January 2001, with the completion of the JSF ORD many of the functions of RQ were transferred to the Systems Engineering Integrating Team (SEIT) under SE.

(b)(6)

[redacted]

Figure 38: JSF Organization as of January 2001.

5.1.5 1999 Replan Effort

In late 1998 and early 1999, it became apparent that each of the contractors were spending funds at a greater rate than was originally planned to stay within their contract amounts. This led to extensive discussions on how to best accommodate these cost overruns. On 29 January 1999, General Kenne and several other Air Force and Navy officials disclosed a potential overrun of over $100 million in testimony to Congress. The initial overrun on the program came from Lockheed Martin and was allocated to three areas: new technologies, the Allison Lift Fan and faulty accounting. In late February, Boeing announced that they were projecting a $35 million cost overrun.

Each of the WSCs was limited to the amount of funds on their contracts. Simply adding more money, in addition to being difficult to find, was also not seen as practical, since an equal amount for each might help the two WSCs unequally. Allowing the companies to make their own investments was also undesirable because of concerns that the contractors would spend too much of their own money in an attempt to win the EMD contract.* In any event, the WSCs were not interested in cost-sharing. In February, both Boeing and Lockheed announced that they would complete their contracts within government funds, removing work on the PWSC designs and Tech Mat. Both Lockheed and Boeing were instructed to submit their new plans by 30 April.

On 4 May 1999, the JSFPO announced that the program would remain on its current schedule and budget by reducing some technology efforts. The announcement stated that:

> The issues on the Joint Strike Fighter have been resolved. Both Boeing and Lockheed will still fly two demonstrator aircraft and demonstrate the critical flight characteristics of the three variants: CTOL, CV, and STOVL. There will be fewer formal design iterations of the Preferred Weapons System Concept (PWSC) that are provided to the government prior to final proposal submittal and some technology maturation efforts have been reduced. Both contractor programs will provide a solid basis for DoD decision making and will still result in significantly reduced risk prior to beginning the next phase of development. Schedules are tight but achievable. Our greatest challenge and that of the contractors is still (as it has been from the program's inception) the complex integration of the flight controls with the STOVL propulsion system. That work will be on-going through the winter of this year and into the first of next year. First flight is still spring of 2000 with the down-select decision in spring of 2001. Any specifics of the contractor's program need to be articulated by the contractor.[9]

Lockheed responded by stating that, "We have agreed to retain Concept Demonstration Program features that will renew the program objective of demonstrating STOVL performance; that is, demonstrate hover to supersonic flight on the same day and on the same flight."[10] Lockheed also announced the removal of a PWSC iteration and announced a design freeze with 230-5. Boeing stated that, "With the current plan we are confident that we will execute our contract on time and on budget. Our plan is very strong, and we will meet all of the original basic requirements of the concept demonstrator program."[11] The WSCs finished their contracted PWSC work in late 1999, but both WSCs are continuing PWSC work off-contract, using independent research and development (IRAD) and bid and proposal (BP) funds.

5.1.6 1999 Defense Science Board (DSB) Report

On 10 June 1999, the Research and Development sub-panel of the Defense Science Board (DSB) Task Force on Defense Acquisition Reform made its final report. With regards to JSF, the panel concluded that the five most important specific issues facing JSF are: 1) a price based contract; 2) the failure to consider the JSF a weapons system; 3) open architecture; 4) maintenance concepts; and 5) a remedy to the loss of operational testing concurrency caused by QDR decision.[12] Each of these are explained below:

* In the ATF YF-22/YF-23 competition, for example, it has been estimated that each of the contractor teams spent $650 million or more of their own money. Northrop lost the competition and, due to the quantity reductions of the F-22 program, even Lockheed has stated that they will not be able to recoup that investment.

On the issue of a price based contact, the DSB suggested that the JSFPO should consider the JSF acquisition program as a candidate for a price based acquisition program. Price-based acquisition is essentially making purchases without reliance upon the supplier's cost information. The intent behind moving to price-based acquisition is to eliminate, to the greatest extent possible, differences between Government contracting and commercial purchasing. Expected benefits from this process include reduced prices for military products (by enabling companies to integrate their military and commercial production lines) and greater access to commercial products, technologies and services. [13]

The DSB viewed the decision not to develop new weapons for the JSF as "regrettable." On this point, the DSB states that:

> It is shortsighted not to have new munitions development considered part and parcel of a major weapons system development. The Department [DoD] should insist on a separately funded but parallel and integrated munitions development effort to insure not only an efficient and effective new weapons system, but also an efficient and effective weapons munitions suite to optimize the combination. It is too late to resize the weapons bay, but rather than settling for two 2000-pound bombs for the near term, the Department should be actively seeking to put 10 to 20 high energy, high lethality, high precision bombs in each of the bomb bays.[14]

The DSB suggested that DoD remedy the omission of new munitions development by either expanding the responsibilities of the JSFPO to include new weapons development, or initiating a parallel weapons development for the JSF to ensure that the weapons system and the munitions are integrated into the platform.[15]

On the subject of open architecture, the DSB suggested that the JSFPO be involved in the formulation of the Joint Technical Architecture (JTA), which is currently under development. The DSB would like to see JSFPO membership on the JTA Development Group, JTA Technical Architecture Steering Group, the Architecture Coordinating Council, and the Defense Information Infrastructure Common Operating Environment Architecture Oversight Group.[16]

The DSB concluded that all U.S. users of the JSF should adopt an "all up" common maintenance and sustainment concept: joint training for all JSF maintenance and logistics personnel; a common condition based maintenance concept; and common practices for daily maintenance. The DSB further stated that there should be a DoD mandate to use common ground equipment packages, training concepts, spares, etc.[17]

Finally, the DSB suggested that the OSD and the services direct restoration of coincidence to the procurement of the USAF/USMC/USN operational test aircraft buy and not follow the QDR mandate that the buy schedule be a sequential annual buy of four aircraft for each service.[18]

The recommendation on the procurement schedule is being implemented, as discussed in Section 5.5.2. The DSB also addressed several other issues such as program stability, modeling and simulation, and requirements creep after the JORD is baselined.

5.1.7 2000 "Winner-Take-All" Review

In January 2000, USD(AT&L) Dr. Gansler asked for a review of the "winner-take-all" strategy. Three senior industry and retired military consultants evaluated the various options during the first quarter of 2000. A government review team – consisting of representatives from SAF/AQ, ASN/RDA, and the USD(AT&L) office of Strategic and Tactical Systems, and the office of Industrial Affairs – also reviewed the potential options during the March to October timeframe. The Government review team, with input from the industry consultants, reviewed the industrial base across three broad areas: tactical airframe, radar and avionics, and propulsion. The review validated the industrial base of the airframe and avionics companies to be solvent through JSF EMD with current programs. Emerging programs such as UAV

development and production were expected to provide sufficient industrial base after JSF EMD. The propulsion system strategy of funding both P&W and GE addressed the engine industrial base.[19]

There was great speculation in the press and by the WSCs that the strategy would be changed to one of teaming between both WSCs, or possibly even competition for production lots or division of the variants. Nonetheless, Dr. Gansler announced on 22 June that the Defense Department had decided to "stay the course." In a letter to the Defense Subcommittee of the House Appropriations Committee (HAC-D), Secretary Cohen wrote:

> The Department has examined a number of options for continuing the JSF program once concept demonstration is completed. These options all assume the selection of a single, winning design. They range from winner-take-all to competition through production. Each option that we have studied offers potential benefits and drawbacks, both tangible and intangible. We will continue to evaluate these options and to develop a comprehensive assessment that our successors can use as they make decisions on the future course of the JSF Program. [20]

The studies found, however, that it was difficult to determine if there will be sufficient non-JSF opportunities to keep the losing JSF contractors' design capabilities and production lines in business. To further address this question and the potential cost savings of competing the production phase of the JSF program, the DoD directed the RAND Corporation to conduct an independent assessment. The RAND report was completed in December 2000. This report addressed potential economic impacts of competing the production phase and the long-term effects of the current JSF acquisition strategy on the industrial base. Dr. Gansler announced that the results of the government review team and the RAND study would be provided to the next administration for their use in determining whether the "winner-take-all" acquisition strategy should be modified.[21] This report was then reviewed and edited during the first quarter of 2001. Congress was briefed on the report in March 2001.

5.1.8 2000 Congressional Actions

Due to delays in flight testing the CDA aircraft, it became obvious in mid-2000 that there would not be sufficient testing of the demonstrators – particularly the STOVL aircraft – to allow a meaningful source selection and downselect for EMD in early 2001. Consequently, Congress reduced the funding requested for JSF EMD by nearly $400 M and added $250 M to the JSF CDP account (referred to as "Dem/Val" in the legislation). This resulted in a six month "slip" to the program, with the source selection decision expected in October 2001, as opposed to the earlier March 2001. A number of other requirements were also levied on JSF in the 2001 legislation, by each of the key committees: [22]

- The House Armed Services Committee required OSD to submit a study of JSF production alternatives and effects on industrial base prior to entering EMD.
- The Senate Armed Services Committee required a report on JSF acquisition strategy and exit criteria (which would be based on the RAND report).
- The House Appropriations Committee mandated that DoD could not develop an ejection seat for the JSF other than those developed under the Joint Ejection Seat Program. This ruled out potential use of the Russian Zvezda K-36 ejection seat.
- The House Appropriations Committee directs that JSF conduct a complete flight test program for the JSF prototypes and perform full evaluation of all flight test results as part of the EMD proposal review. It also required that DoD continue with the "winner-take-all" and alternate engine strategies.
- The Appropriations Conference required OSD to submit a report on the status of JSF program with FY02 budget request. It also reiterated the HAC language and that the added CDP funds only be used for fully executing the "Dem/Val" phase and completing all planned and necessary testing. It further directed that all flight-testing be completed and fully evaluated prior to the selection of a JSF EMD design.

- The Authorizations Conference levied a requirement for OSD to conduct a study of final assembly and checkout alternatives for JSF after the EMD selection (this was also conducted by RAND). The Secretary of Defense had to submit a report by mid-December 2001 describing the exit criteria from "Dem/Val" and entry into EMD. The committee further stated that JSF could not be approved for EMD until the Secretary of Defense certified:
  - the accomplishment of exit criteria established in the report;
  - the technological maturity of key technologies for the program is sufficient to warrant entry into EMD; and,
  - STOVL variant selected for EMD has successfully flown at least 20 hours.

5.1.9 Program Protection & Security

During CDP, the Security Directorate (SC), led by [redacted] USN, developed the Program Protection Development Plan (PPDP) and released it in January 1998. The PPDP was based on the 1996 JSF Security Master Plan, which was the blueprint for security requirements for CDP. The PPDP identified and described JSF security philosophy, methodology and a schedule of products to be developed over the next three years of the program. SC is currently comprised of three areas: Foreign Disclosure, Program Protection, and Security Operations. Program Protection is divided into several working groups: Cost, Cryptographic, Systems Security Engineering, Technology Assessment, and Certification and Accreditation.

Foreign disclosure operations took on an added importance as new international partners joined the program: currently 6 partners and 3 FMS participants. U.S. policy regarding transfer of technology varies by country and delegations from SAF/IA for release authority reflected these differences. In addition, each foreign partner nation had negotiated a different form of participation based on their unique needs and financial contribution. All of these things affected security and foreign disclosure operations. In recognition of the growing importance and complexity, Maj (later Lt Col) [redacted] USAF, was assigned to the JSF Program in August 1998 for the newly established role of Chief, Foreign Disclosure and Deputy Security Director. Additional support contractors were added to assist Lt Col [redacted] and the International Directorate. Other international participants are also expected to join the program, each with their specific needs.

The program protection effort has likewise matured as the JSF Program has progressed. The Program Protection IPT (P2IPT) is headed by Capt. [redacted] USAF, with the intent to address, integrate, and validate program protection, system security engineering, and operational security requirements, policy and procedures in support of the JSF mission. In early 1997, following the CDP contract awards, increased emphasis was given to finalizing the list of JSF Critical Program Information (CPI). CPI is defined as "components; engineering, design or manufacturing processes; technologies; system capabilities and vulnerabilities; and other information that give the system its unique capability or limit the ability of other countries to reproduce the essential capabilities or mission."[23] CPI is the basis for overall program protection efforts. At the same time the PPDP was being released, the JSFPO approved the final CPI list, generated by the Technology Assessment Working Group. Additional inputs were provided by the WSCs and the propulsion manufacturers. The final list was reduced to 48 CPI items (from an original total of 66) and approved with the PPDP. This listing was used by the supporting intelligence and security agencies in preparing their threat assessments for the JSF Program.

The National Security Agency (NSA) has designated two people in direct support of the P2IPT. The NSA and JSF signed an MOA in July 1998, concerning Information Systems Security Engineering Support to the JSF Program Office. The NSA supported the development of the Telecommunication Security Requirements Directives and the Functional Security Requirements Specifications. These documents will be included in the EMD contract to ensure the contractor's overall air system development is in compliance with the security requirements contained therein in order to receive NSA's endorsement.

A Cryptographic Working Group, comprised of JSF, NSA, Space and Naval Warfare Systems Command (SPAWAR), Electronic System Center (ESC), and the WSCs was formed and tasked to address JSF specific cryptographic issues. This process is critical to ensure the cryptographic systems employed by the JSF receive NSA endorsement. The Certified TEMPEST* Technical Authority (CTTA) must certify systems that process classified or sensitive national security information. The P2IPT along with the CTTA, are establishing the TEMPEST requirements for the operation of the JSF.

The P2IPT has employed the Common Criteria method of Certification and Accreditation (C&A), which calls for Protection Profiles and Security Targets. The Common Criteria is an international standard for trusted product evaluation. The original countries that formed the basis for Version 2 of the Common Criteria are Canada, France, Germany, Netherlands, United Kingdom and United States with both the National Institute for Standards and Technology (NIST) and NSA participating. The Common Criteria will replace the Trusted Computer Security Evaluation Criteria (TCSEC) "Orange Book" for Government Trusted Product Evaluations. The National Information Assurance Program (NIAP) will serve as the reviewing body for all U.S. evaluation laboratories (NIAP consists of representatives from NSA and NIST). This method has never been applied to a system as large as JSF and is more flexible than the DoD Directives spelled out in the Orange Book.

The WSC's, in close coordination with the JPO, will produce a System Security Authorization Agreement (SSAA) for each Automated Information System (AIS) boundary, which they will establish in accordance with their respective avionics and weapon system design/architecture. The SSAA is a single source for all information pertaining to Certification and Accreditation (C&A) by the Designated Approval Authority. The SSAA template and subsequent SSAAs published by the contractor in EMD will include the JSF Security Policy. The JSF Security Policy drives the requirements in the JSF Model Specification, discussed in Section 5.2.9.

USD(A&T), in a letter dated 20 July 1998, appointed the JSF Program Director as the Designated Approval Authority for JSF systems. The Program Director coordinates certification testing with users and involved agencies and appoints the JSF Certification Authority(s). In December 1998, an MOA was signed by JSF; NSA; SAF/AQL; N-88; Office of the Chief of Naval Operations, Special Programs Division (N-89); and Headquarters USMC, Deputy Chief of Staff for Aviation; concerning system security certification and accreditation for the full life cycle of the JSF weapon system. This MOA established the senior-level security Certification and Accreditation Advisory Group (CAAG) which is chaired by the JSF Program Director. The CAAG will provide C&A oversight, through which the accreditation authority of the participating organizations will be executed.

Another element of the P2IPT effort involves System Security Engineering (SSE), which applies scientific and engineering principles through the system engineering process to identify and reduce system susceptibility to damage, compromise, or destruction. It identifies, evaluates, and eliminates or contains system vulnerabilities to known or postulated security threats in the operational environment. This involves incorporating security requirements into the weapon systems engineering architecture. A key difference between SSE and Program Protection is that SSE addresses those threats against the system during deployment, operations, support, and involves the integration of security considerations into the systems engineering process early in the design. This ensures the total system is evaluated for known or potential system vulnerabilities and that the system is designed in a cost effective manner to reduce the probability and severity of all security vulnerabilities.

In a policy dated 4 February 1999, USD(A&T) directed that weapon system programs that are likely candidates for export consider applying anti-tamper techniques in their weapon system design. Anti-tamper

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* Telecommunications and Electrical Machinery Protected From Emanations Security (TEMPEST) is concerned with limiting unwanted electromagnetic emissions from data processing and related equipment to prevent eavesdropping.

protection is the collection of mechanisms, design features, and manufacturing techniques that minimize the probability of undetected penetration of an equipment and compromise of classified information. The equipment design and physical security controls afforded these devices must be sufficient to assure a very high probability of detecting tampering attacks and thwarting attempts to obtain classified or sensitive information either directly or indirectly. Further, there must not be any recoverable sensitive information remnant in the protected device following a penetration. The System Security Engineering Working Group continually evaluates technical areas in the design and architecture where anti-tamper techniques can be incorporated to protect JSF technology and classified information. System Security Engineering will be applied to new developments and to modifications of existing systems.

Protection cost also constitutes a key element of the program protection planning effort. Over the course of the CDP phase, the Security Cost Working Group has been developing a life cycle cost estimate of security measures. This estimate will serve as the principle tool for security risk management decisions and designing cost effective security countermeasures. Two main categories of costs are addressed in the estimate:

- **Industry costs**—those security cost incurred by industry and passed on to the government as part of the contract price. This includes costs identified specifically with that contract and are charged directly to it as well as indirect costs not identified with a single, but rather two or more contracts.
- **Government costs**—the costs that government agencies will incur in protecting the weapon system and its technology throughout its life cycle.

The biggest security cost challenges are the lack of historical data and the inability of current accounting systems, both government and industry, to break out security cost data. There was no information available for capturing security costs under other acquisition programs: it simply hadn't been done before. The Security Cost Working Group collected security cost data from industry and government through extensive on-site surveys of physical and personnel security functions. Survey targets included flight squadrons and maintenance facilities, Air Force and Navy test centers, operational bases within the U.S., the aircraft carrier USS John C. Stennis (CVN-74) and the USS Bataan (LHD-5) at sea, and the North Atlantic Treaty Organization (NATO) airbase in Aviano, Italy. Industry costs were derived from thorough analyses of direct and indirect costs with the assistance of major contractor accounting staff. The Security Cost Working Group surveyed existing strike fighter weapon systems to identify baseline security costs. Operational Air Force, Navy and Marine strike units were evaluated, including an Air Force F-117 squadron to capture the security costs of an operational low observable strike fighter.

As a result of all these efforts, JSF Security issued the preliminary version of the Program Protection Plan (PPP) in September 1998 to government and industry, with the second version issued in November 1999. The PPP includes: the Program Protection Development Plan, Security Classification Guidance, a Defense Security Services Program Wide Assessment, Technology Assessment, Technology Assessment/Control Plan, Anti-Tamper, Security Cost Model, Preliminary System Security Concept, System Security Authorization Agreement, and the Cryptographic Key Description Document. The goal of the PPP is to ensure the development and fielding of an uncompromised weapon system while upholding the four pillars of JSF: Affordability, Survivability, Supportability, and Lethality. The PPP identifies the CPI and creates an integrated management plan permitting implementation of specific security measures ensuring the protection of the JSF weapon system CPI and sensitive/classified information throughout the acquisition process.

Planning is now underway to address the security and foreign disclosure issues associated with foreign participation in the EMD phase of the program and ongoing negotiations with potential EMD partners, since the current MOA/MOUs expire at the end of CDP. The Technology Assessment/Control Plan (TA/CP) was updated in preparation for Milestone II, and planning commenced to prepare for EMD negotiations with the international partners. The 1998 TA/CP was updated to include the current PWSCs;

the approved CPI list from the Technology Assessment Working Group (discussed above) was used as well as other JSFPO sources, open source searches from the world wide web, OUSD(A&T), DDR&E, and existing National Disclosure Policy. The Technology Assessment portion was completed and reviewed by SAF/IA, OUSD(A&T), DDR&E, and the JSFPO. The Control Plan portion will be completed in early 2000 to support country negotiations and draft EMD disclosure policy. International Participation is expected to continue to grow during EMD and beyond.

In preparation for EMD, the P2IPT has completed the Security Operational Requirements, the Model Specification Terms, the Manning Requirements, and drafted the JSF Security Statement of Objectives. In addition, the Security Cost Model EMD strategy includes having the WSCs report their EMD security costs. This information will allow the Program Director to use the CAIV methodology when making security decisions.

5.1.10 Flight Test Planning

Consistent with the shift in focus of the CDP, the JSF Program formed the System Test IPT, led by (b)(6) [redacted] of NAWCAD Patuxent River, during CDP source selection. The System Test IPTs' purpose is to tackle test issues associated with the Concept Demonstration test program, as well as Test and Evaluation (T&E) planning for EMD. Avoiding the "business as usual" syndrome, the JSF test program is contractor-led and the government test sites are considered flight test "support" organizations. Therefore, the government provided the necessary testing facilities for Tech Mat projects, prototype model development, and component evaluations. The System Test IPT has developed a flight certification plan, a signed Interim Test and Evaluation Master Plan (ITEMP), and MOAs among Government agencies. Furthermore, the IPT has identified Government furnished equipment, updated program introduction documents, and planned the test team concept of operations. Test pilots and engineers from the U.S. Navy, Marine Corps, Air Force, and UK are provided to the program through the System Test IPT. Specifically, the Strike Aircraft Test Squadron of the Naval Air Warfare Center Aircraft Division has provided four pilots and six engineers, and Edwards Air Force Base has provided two pilots and six engineers funded through the Systems Test IPT.

The System Test IPT formed the Combined Test Working Group (CTWG) in late-1996 to develop the Test & Evaluation Master Plan (TEMP). It is a working level IPT with representatives from industry and the government. The primary purpose is to develop a balanced test approach, using modeling and simulation to the greatest extent possible, while fully integrating the Developmental Test (DT) and Operational Test (OT) communities. To develop the Milestone II TEMP, four sub-working groups were formed from the CTWG in September 1998: Modeling, Simulation, And Analysis; Live Fire Test & Evaluation; Developmental Test/Operational Test; and JIRD. The JIRD and DT/OT working groups were replaced with the Mission Effectiveness and Supportability Working Groups in late 1999. Each of these groups researches and writes sections of the TEMP, with the signatory representatives voting on specific wording. A Draft TEMP was released for comment on 22 November 2000, and the final TEMP was released in early 2001.

In 1998, the System Test IPT began developing an integrated government/WSC roadmap to first flight in 2000. This included Flight Certification, First Flight Readiness Review, Concept of Operations, and chartered an independent review team and safety review board. The System Test IPT organized the Joint Test Force, aligning and integrating dedicated pilot and engineering teams with the WSC test teams.

In 1999, flight certification and clearance processes were developed, working in concert with the services and contractors to streamline CDA flight test. The concept was to provide an initial flight envelope within which the contractors (in theory) could execute their entire CDP flight test operations. A process was developed to adjust the flight clearance and envelope in response to a hardware or software change. The System Test IPT has worked closely with the various field activities to guarantee unique facilities are in place for the test program, to arrange necessary GFE and support equipment, and to allot hangar and office space for the integrated test team. Issues dealing with chase flights, pilot proficiency, instrumentation and range requirements (telemetry, real-time processing, etc.) were also coordinated.

During early 2000, the First Flight Readiness Reviews were held, leading to approval for the first flights of the CDA demonstrators. During the Fall and Winter of 2000, FFRRs were held for the X-32 CTOL and the X-35 CTOL and CV aircraft.

5.2 Requirements

Requirements highlights during 1997-2000 included the following:

- Release of the second and third iterations of the COPT and JIRD, as well as the draft and final JSF Operational Requirements Document (ORD)
- A significant increase in the pace of mission-level modeling & simulation activities, including Virtual Strike Warfare Environment (VSWE) and air-to-air combat simulations demonstrations
- Release of the first draft Operational Employment and Support Concept Document (OESCD)
- Initiation of the Maintainer in the Loop (MxITL) process and establishment of the Maintenance Systems Advisory Panel (MSAP)
- Validation of the Joint System Threat Assessment Report (JSTAR) in April 1997, as well as an update in February 1999, the first ever foreign releasable STAR in July 1998 and an update to the foreign releasable STAR in January 2000
- Publication/coordination of the first JSF Joint C4I Support Plan Draft—heralded by OSD as a model way of doing business
- Development and release of the Joint Model Specification (JMS)

5.2.1 Threat and C4I Activities

A System Threat Assessment Report (STAR) and a Joint Command, Control, Communications, Computers, & Information Support Plan (JC4ISP) are required by DoD 5000.2R prior to Milestone II. The Threat/C4I Division in the JSF Requirements Directorate is headed by (b)(6) [redacted] is responsible for the planning, coordination, and execution of US Intelligence Community activities that support the development, publication, and distribution of the JSF STAR, as well as all other threat support activities related to the JSF Program.

In 1994, the JSFPO established the JSF System Threat Working Group (JSTWG) to provide tailored intelligence to support key program products such as the ORD and JMS. The JSTWG is chaired by the JSFPO and has nearly 100 representatives from all the cognizant US Intelligence Community agencies and Service Intelligence Production Centers, research laboratories, test and evaluation centers, weapons and tactics ranges, as well as other DoD acquisition programs (e.g. F-22 and F/A-18E/F), Federally Funded Research and Development Centers (FFRDCs), and industry. The JSTWG is the Program's single point of contact to the US intelligence community for all threat-related issues and acts as the conduit for all intelligence information, products, threat assessments, and data requirements to the JSF Program and its industry partners.

Within the JSTWG are the Executive Steering Committee and the Threat Production Team. The Executive Steering Committee is the decision-making body of the JSTWG for the initiation and/or acceptance of program-generated US Intelligence Community Production Requirements, to include their prioritization and submission to the DIA for validation. The Executive Steering Committee is chaired by the JSFPO and has representatives from all five DoD intelligence production centers (e.g., DIA, National Air Intelligence Center (NAIC), DIA/Missile and Space Intelligence Center (MSIC), Office of Naval Intelligence (ONI), and National Ground Intelligence Center (NGIC)), with USAF 497th Intelligence Group, Central Intelligence Agency (CIA), National Imagery and Mapping Agency (NIMA), and NSA collaboration. The Threat Production Team is the "action arm" of the JSTWG. Its membership is identical

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to the Executive Steering Committee, but is co-chaired by NAIC and ONI on a revolving basis. It is responsible for production, validation, and tracking of Production Requirements.

The DIA-validated JSTAR is the authoritative threat reference document used by the Program (government and industry alike) for establishing the validated future threat environment at IOC (2010) and IOC+10 years (2020). It is published in accordance with DoD 5000.2R requirements under the auspices of Department of Defense Intelligence Production Program. It is produced by NAIC and reflects the DoD Intelligence Community position with review and inputs of the CIA. The JSTAR undergoes an extensive updating, review, and validation process every 18 months under the direction of the JSF STAR Threat Steering Group. The Threat Steering Group is chaired by the USAF 497th IG and its membership includes the DoD Intelligence Community, the service requirements and operational test commands, and the JSFPO.

The first JSF Joint System Threat Analysis Report (JSTAR) was developed and validated by the DIA in April 1997, and then updated in February 1999. In the interim, the first-ever foreign releasable STAR was produced for the JSF Program and released in July 1998 and updated in January 2000. Since the STAR must be updated every 18 months, a third update is scheduled to be released in April-2000 with a subsequent foreign-releasable version to follow. Excerpts from the 1999 STAR executive summary are included here:

> By 2010 our warfighters will be operating in a threat environment that is populated by technologically sophisticated and highly lethal weapons systems integrated by advanced command and control architectures. These advanced weapons systems are becoming more affordable and easier to employ and therefore more widely proliferated. [DIA] predicts that by the year 2005 the number of countries possessing SA-10/12 class surface-to-air missiles (SAMs) will increase by 50 percent. These systems have a three-fold increase in capability over systems faced in Operation Desert Storm (ODS). It is also predicted that the number of countries flying advanced fighter aircraft armed with highly capable air-to-air missiles (AAMs) will increase by 25 percent.
>
> There are several key threat weapon system developments and trends which adversely impact the *survivability* of existing US and NATO air forces. **SAMs (long-range, medium-range, and man-portable air defense systems or MANPADS) constitute the most serious threats to US and NATO airborne systems.** Foreign SAMs deployed by 2010 will have greater mobility, increased accuracy, longer detection ranges, and speeds approaching Mach 8. They will be coupled with acquisition and tracking radars that have greater peak power, multiple modes, and faster computer processing giving them multiple target engagement capability and improved capability against reduced signature targets. Major improvements include active seekers for long- and medium-range SAM systems and imaging (scanning/staring) seekers for short-range and MANPAD systems. At the same time, many of these SAM systems will be easier to employ with less training required. Next-generation anti-aircraft artillery (AAA) systems will also benefit from many of the same technological advances. Tactical lessons learned from ODS may be incorporated into employment doctrine increasing the lethality of these SAM and AAA systems and reducing the effectiveness of current day Suppression of Enemy Air Defenses (SEAD).
>
> Future threat aircraft will incorporate a number of advanced technologies. The next generation of foreign aircraft designs will incorporate, to varying degrees, low-observable technologies which will reduce radar detection ranges, decrease tactical response times, and shrink weapons envelopes. They will be more highly maneuverable employing fly-by-wire configurations and fitted with more powerful, efficient, and reliable engines with some incorporating thrust vectoring nozzles. State-of-the-art avionics, such as sophisticated multi-mode radars, automated countermeasures, navigation and targeting systems utilizing global positioning data will reduce adversary pilot workload and increase situational awareness. Many aircraft will also have the potential to be equipped with improved infrared, radar and radar-homing air-to-air missiles, possibly fitted with dual-mode seekers and coupled with helmet-mounted aiming systems giving an extreme tactical advantage over current US and allied systems. Multiple aircraft will be able to share targeting information and receive command and control instructions from ground stations via data link. **The combination of these capabilities in future threat aircraft poses a significant threat to US and NATO airborne systems.**
>
> Concurrent with the potential adversary air defense system developments outlined above are technological advances which will adversely impact the *lethality* of existing US and NATO air forces. Tomorrow's threat

> Integrated Air Defense Systems (IADS) will be much more difficult to disrupt. Distributed processing of large volumes of encrypted digital data passed via hardened, buried fiber optic cable will greatly reduce the vulnerability of many IADS. The ability to identify and "kill" key IADS nodes may be significantly reduced. Additionally, future IADS design may limit the impact of destroying individual IADS nodes on overall IADS performance. The synergistic combination of multispectral SAM and AAA fire control systems, increased mobility, and the use of Camouflage, Concealment, & Deception (CC&D) (to include reduced target signatures, use of decoys and jammers, etc.) will greatly increase the survivability of threat IADS while reducing the effectiveness of allied SEAD operations. Additionally, the application of signature reduction techniques, use of CC&D, and/or increased mobility will reduce the ability of allied air forces to effectively identify, track, and destroy key threat target sets to include ballistic and cruise missiles, Weapons of Mass Destruction (WMD) facilities, and other time-critical targets.[24]

(b)(6) [redacted]he JSF C4I IPT Lead, is responsible for the planning, coordination, integration and execution JSF C4I IPT activities that contribute to the development of the JSF Joint C4ISP. She is also responsible for the production, publication, and distribution of the C4ISP. To fully address the requirement for a JC4ISP, the JSF Program Office created a full-time government position and invited DoD, Joint Staff, service and national agencies to participate in the JSF C4I IPT's plan process. This support and participation was critical to the process for several reasons. First, the JSF C4I IPT recognizes the need to interface with those responsible for developing and maintaining C4I architectures; these organizations also have access to the documentation needed to develop the plan. Second, the JSF Program wanted the active participation of these organizations in JSF activities such as MS&A, ASAP meetings, and FPT events to help define JSF C4I requirements and identify on-board/off-board trades needed to refine JSF avionics capabilities and on-board architectures. Finally, the JPO wanted to promote and obtain C4I community consensus on the C4I concepts and architectures that formed the basis for the JC4ISP.

A C4ISP Working Group was established in February 1997 to formulate the JSF C4ISP vision and approach used in developing the JSF Joint C4ISP. The C4ISP Working Group was elevated to IPT status in August 1997. It includes representation from DoD agencies—including the Assistant Secretary of Defense for C3I (ASD/C3I), C4ISR Integration and Supportability Agency (CISA), DIA, Defense Information Systems Agency (DISA), and the Defense Airborne Reconnaissance Office (DARO)—as well as National Agencies such as the NIMA, the National Reconnaissance Office (NRO), and NSA, DoD, Joint Staff, and the services. The JSF WSCs and MIRFS contractors are also members of the IPT. In January 1998, a Coalition Working Group was established to address C4I interoperability issues with the JSF international partners. System of Systems issues are worked jointly by the C4I IPT in RQ and the Mission Systems IPT in SE.

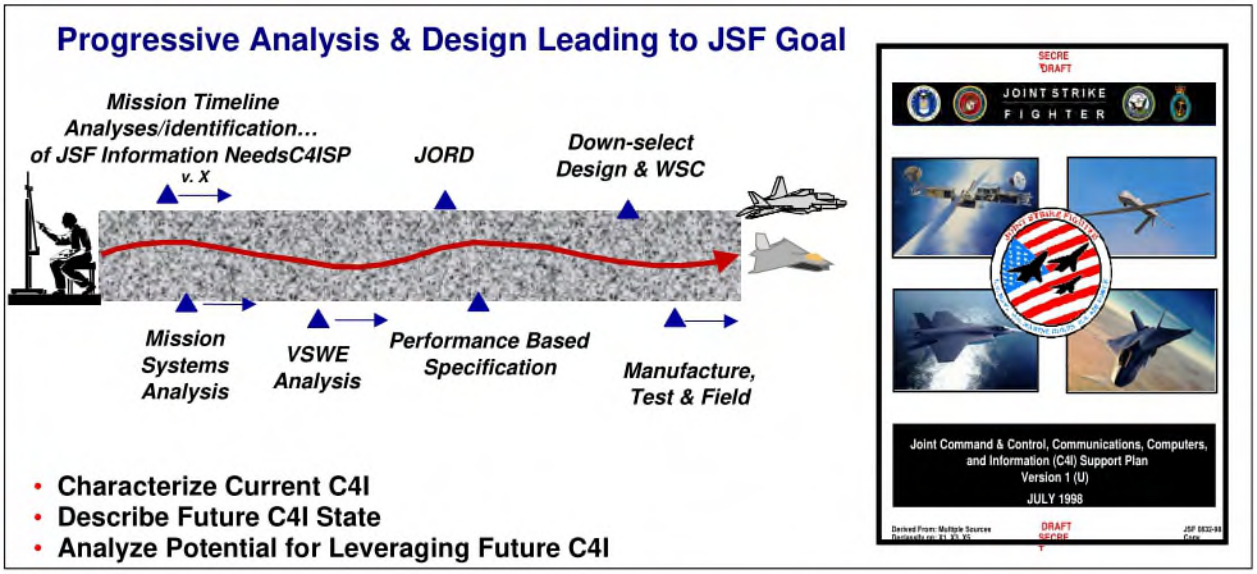

Figure 39: C4I Path to the EMD Joint C4I Support Plan

Since February 1997, the JSF Program Office (and the JSF C4I IPT in particular), has engaged in a series of activities, shown in Figure 39, that will help to characterize the current C4I infrastructure, describe the future C4I state, and analyze the potential for leveraging future C4I capabilities. All of these elements are captured in the JSF Joint C4ISP. These activities included: the characterization of JSF operational mission timelines from both Joint and service-unique perspectives; Mission Systems IPT analyses that resulted in the characterization of JSF notional avionics suites; and support to FPT and VSWE events conducted between March 1997 and November 1998 that helped characterize the contribution of JSF on-board and off-board C4I capabilities. Inputs to the draft JORD were staffed and an interim version of the Joint C4I Support Plan was distributed in early 1999.

The JSF C4I IPT's approach to the development of a Joint C4ISP is unique in that it transcends the traditional intelligence surveillance and reconnaissance construct to encompass all combat information including these areas plus navigation, weather, and logistics information. JSF is using this approach to quantify bandwidth requirements, define on-board capabilities, and assess the value added of emerging information systems technologies. The purpose of the JSF C4I Support Plan is to:

- Articulate and document a conceptual architecture that is based on Joint Vision 2010's information dominance tenet and emerging National, DoD, Joint, and service C4I agency concepts
- Obtain C4I community consensus/validation of this conceptual architecture
- Identify JSF Information needs and attendant C4I support requirements
- Assist in the definition of JSF on-board capabilities through the JORD and PBS processes
- Mitigate JSF WSC risk by providing a baseline conceptual architecture

The initial interim version of the JSF Joint C4I Support Plan addresses U.S. only operations and contains all of the products or elements prescribed by ASD/C3I's C4ISR Architecture Framework document. The operational missions analyzed in the first version of the plan focus on strike-related missions, interdiction, close air support and SEAD. It also addresses the defensive counter-air (DCA) mission. The plan was published and distributed to national, DoD, Joint Staff and service agencies, as well as to ACAT I and II programs (e.g. CVNX, F-22, Airborne Laser, DD-21) in April 1999. The plan was submitted to SAF/IA for Foreign Disclosure review and release to JSF international coalition partners in accordance with National Disclosure Policy requirements. The plan will continue to evolve as the JSF

Operational Employment and Support Concept Document (OESCD), service-specific Concept of Operations (CONOPS), and supporting C4I architectures mature.

Throughout 1999 the JSF C4I IPT team engaged in a series of activities geared towards the planning and execution of VSWE events, the refinement of the JSF ORD, the continuing evolution of the JC4ISP, and the development of the JMS. In order to address JSF information needs in a coalition environment, the IPT established a multi-national C4I working group in January 1999. Group participants include Canada, Denmark, Italy, Netherlands, Norway, and the United Kingdom. As a result of JSF Program Director meetings with senior officials from ASD/C3I and service acquisition officials, the IPT also provided a series of JSF C4I Support Plan presentations aimed at fostering continuing C4I community consensus on the proposed JC4ISP conceptual 2010 architecture and support for the JC4ISP development process. Finally, the IPT also supported the 497th Intelligence Group's Air Force JSF Intelligence Support Plan (ISP) working group by reviewing their draft ISP and providing inputs. This process ensures Air Force unique requirements are addressed in the JSF C4ISP.

In February 1999, the C4I IPT and the NRO co-hosted a JSF Imagery for Lethality (JIFL) event at China Lake (this and the VSWEs are described in Section 5.2.5). This event evaluated the utility of EO, IR, and SAR imagery in the JSF mission planning and mission execution phases. The C4I IPT support to VSWE 4 events consisted of characterizing the 2010 conceptual C4I support environment during each mission phase, briefing and debriefing event pilots, and providing C4I expertise as required to ensure JSF pilot understanding of the C4I environment. Off-board imagery and/or target coordinate information supplemented the study of notional avionics suites in its contribution to mission effectiveness. In April, the IPT supported the planning, testing, and integration of C4I functionalities into the modeling environment for VSWE 4. This event focused on the Close Air Support (CAS) mission and addressed the value of C4I products in the cockpit. Of interest to the OAG was VSWE 4's demonstration of the command and control relationship between the JSF pilot and the Forward Air Controller (FAC). It addressed the issue of JSF weapon employment where the FAC does not have or is unable to maintain visual contact with the JSF. The event provided insight into the contribution of on-board avionics and off-board C4I to JSF mission effectiveness. These insights facilitated the ability to articulate and justify C4I requirements in the draft JSF ORD. VSWE 5 focused on the use of off-board information to enhance the lethality of the JSF. Off-board imagery and/or target coordinate information supplemented the study of notional avionics suites in its contribution to mission effectiveness. At the end of June, the IPT supported VSWE 6 planning activities. This event examined command and control aspects of combat mission dynamic re-tasking in response to time critical targets and operations in a multi-national environment.

The JSF JC4ISP was presented to the RADM Robert Nutwell, Deputy ASD/C3I, on 8 June 1999. The briefing highlighted the need for a focal point for C4I architecture development that supports ACAT I, II, and III programs. As a result of the briefing, RADM Nutwell stated the JSF JC4ISP would serve as a baseline for future ASD/C3I efforts to assist acquisition programs. He also requested the briefing be given to senior ASD C3I, Joint Staff, and service members. All of these briefings were well received and all expressed their support for the JC4ISP content and development process. In addition to all of these efforts the IPT continued work on Version 2 of the JSF JC4ISP.

5.2.2 COPT II / JIRD II

The second iteration of COPTs was completed during the spring of 1997. While COPT I had consisted primarily of a collation of the various contractor CDDR trade study results, COPT II represented a much more focused effort to define the trade space within and between the four requirements pillars of lethality, survivability, supportability, and affordability. The major studies are shown in Table 14.

Table 14: COPT II Studies During 1996-97[25]

Air Vehicle Performance Studies	Mission Systems Performance Studies	Supportability Studies	Affordability Studies
• A/A Acceleration • A/A & A/G RCS • A/G IR Signature • A/G ECM • A/A & A/G Instantaneous G • A/A & A/G Sustained G • Internal Payload • A/G Target Set Accuracy	• A/G Payload • A/G Target Set Accuracy • Ballistic Weapon Accuracy • GPS/INS Weapon Accuracy • Navigation Accuracy • A/G Target Acquisition & Identification • A/A Target Acquisition & Identification • Collateral Damage • SEAD • ECM • ECCM • ESM	• Inherent Availability	• URF Cost • O&S Cost

COPT II supported the development of the second JIRD II, which was released on 27 June 1997. The first JIRD, released in August 1995, had primarily addressed the major "mold line drivers" such as range, payload, and very top-level definitions of speed, maneuverability and signature levels; plus unit recurring flyaway (URF) costs and anticipated procurement quantities of each JSF variant. JIRD II included more detail in all of the JIRD I areas, and also began to define LO, avionics and supportability requirements. JIRD II contains mission need summaries, operational concepts, and support concepts for the USAF, USN, USMC, and RN. The URF figures in JIRD II were identical to those stated in JIRD I, while the procurement quantities were adjusted slightly in accordance with the QDR results. The URF targets and the new procurement quantities are shown in Table 15.[26, 27, 28]

Table 15: Average URF Cost Targets and Procurement Objectives in JIRD II

Variant	URF Target (FY94$)	Quantity	Service
CV	$31–$38 M	480	USN
CTOL	$28 M	1763	USAF
STOVL	$30–$35 M	609	USMC
		60	UK RN
	Total:	2912	

The threat analysis contained within JIRD II was very similar to that found in JIRD I with the exception that it now referenced the JSF JSTAR, dated April 1997, which became the single, authoritative threat reference document (see Section 5.2.1). Tactical aircraft threats mentioned within JIRD II include the development of the French Rafale, Russian Su-35/37, S-37, Swedish Gripen, the multi-national Eurofighter-2000, Chinese F-10, and the next generation Russian fighter project, the MFI.

JIRD II also defined the requirements for JSF unit and LCC. Significant cost reductions in both of these fields are essential to the JSF Program. The lethality of the JSF is judged by many criteria, which in the end lead to an increase in the expected kills per pass/kills per sortie. On the subject of payload, the JSF must be capable of carrying an array of weapons internally. However, it must also be capable of carrying an array of systems externally. JIRD II further stated that JSF must be operationally compatible with CVN and CVX

class carriers. Furthermore, JIRD II issued the USMC's basing requirements indicating how the STOVL variant must operate in order to be useful to the USMC.

Many trade studies are still being conducted. The WSCs perform the underlying engineering and cost analysis, and provide the JPO with "carpet plots" which illustrate the sensitivity of cost and capability (i.e., selected Measures of Performance and Measures of Effectiveness) to variations in requirements (see Figure 40). The carpet plots can also illustrate how different requirements can be traded off against each other to achieve similar effectiveness at the lowest possible cost. The JSF Cost IPT performs a "sanity check" of the contractors' analyses and results, and collates the work of the different contractors. The resulting information gives the warfighters insight into the cost/performance sensitivities as they develop the JIRDs. They can see, for example, where a small reduction in a requirement can yield a large cost savings, or where the performance could be increased with minimal impact on cost.[29]

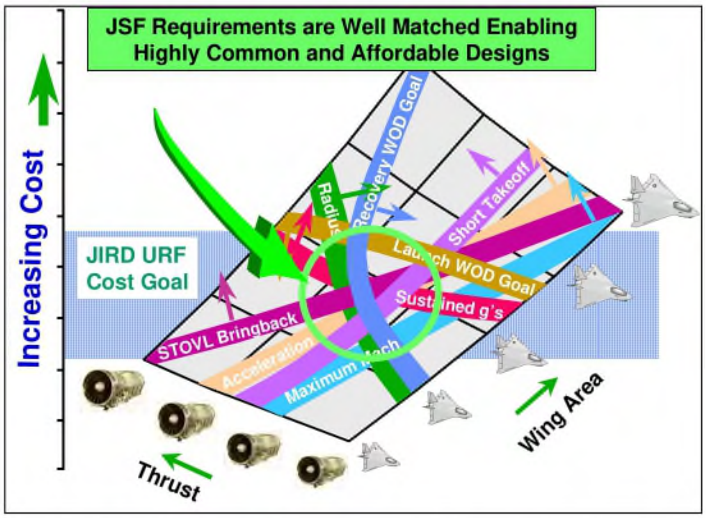

Figure 40: Notional Carpet Plots Showing the Available Design Space

The contractors also present "high-end" and "low-end" concepts to give the warfighters insight into the possibilities that exist both above and below the baseline weapons system concepts, in terms of cost and capability. It was a challenge to initiate this process, because historically performance has always taken precedence over cost. Contractors were given cost targets, but failing to meet the cost targets was never as egregious as failing to meet performance targets. Contractors were therefore reluctant to even show their "low-end" concepts, because in many cases those concepts failed to meet the minimum required performance parameters. Contractors typically felt that showing these low-end designs to a program office might jeopardize their competitive position. This reluctance had to be overcome in the JSF Program. Contractors had to be assured that the whole exercise was intended to provide the warfighters with insight into the cost/performance tradeoffs, and would not be used as a competitive selection tool.[30]

While it is not possible to evaluate the cost impact of every requirement, the COPT process aims to identify the key cost or design drivers and examine those requirements in detail to evaluate the cost and performance sensitivities. In fact, one of the lessons from COPT II was that it is very important not to analyze everything, but to intelligently focus on the most important requirements, so as not to over-burden the WSCs or generate so much data that it becomes difficult to extract useful information.

Another lesson learned from COPT II was that the JSF Cost IPT could not perform an "independent analysis" of every tradeoff to verify the contractors' work. The number of parameters involved in the trade studies would make it prohibitively labor-intensive. Instead, the Cost IPT reviews the contractors' methods

and the credibility of the input data. If these are satisfactory, then the JPO can simply accept the contractors' results.[31]

The ultimate goal of the COPT process was to achieve closure between required capabilities and weapons system costs, prior to the final JORD release. The draft JORD was completed in April 1999, and the final JORD was signed by the JROC in March 2000. Areas of emphasis in the successive releases are illustrated in Table 16.[32]

Table 16: JIRD/JORD Emphasis[33]

JIRD I	JIRD II	JIRD III	Draft JORD
• "Mold line drivers" • Unit flyaway cost	• Aero performance • LO • Avionics • Supportability • Unit flyaway cost	• Detailed avionics trades • Detailed supportability trades • LCC	• Refined supportability requirements • System of systems and avionics trades • Mission planning & training • LCC

5.2.3 COPT III/JIRD III

COPT III studies were conducted from early 1997 to mid-1998. Again, the amount of specificity increased as shown in Table 17.

Table 17: COPT III Studies During 1997–98[34]

Air Vehicle Performance Studies	Mission Systems Performance Studies	Supportability Studies
• A/A RF survivability • A/G RF survivability • Spike trades • Direct attack survivability • AIM-9X effectiveness • A/A IR survivability • A/G IR survivability • Vulnerability • Optimal payload • Small bomb study • Advanced gun study • Performance & flying qualities	• MWS "time-to-go" (TTG) • Defensive ECM • Avionics QFD • Offensive ECM • A/G target set accuracy • Target acquisition/recognition • AIM-9X targeting • GPS/INS weapon accuracy • Mission time line analysis	• Manpower • R&M • Prognostics & health monitoring

JIRD III was issued on 19 October 1998 and continued to expand on the baseline requirements for the JSF previously set in JIRD I and II. JIRD III issued many desired minimums for the JSF in all areas of the aircraft. It set the JSF unrefueled combat radius with internal fuel and payload at 500 nm for the CTOL design and 450 nm for the STOVL design. JIRD III also stated that the JSF will have an internal advanced gun optimized for air-to-ground with a secondary role of air-to-air.

5.2.4 Simulation-Based Acquisition

In March 1998, recognizing the successes of the JSF and other programs, USD(A&T) endorsed a cooperative initiative by the Director, Test, Systems Engineering and Evaluation (DTSE&E) and the Defense Modeling and Simulation Office (DMSO) to develop a roadmap to accelerate the use of simulation in the acquisition process. This concept has become known as Simulation Based Acquisition (SBA), for which JSF has been designated a DoD model program. The purpose of SBA is to provide an acquisition process in which DoD and industry are enabled by robust collaborative use of simulation technology that is integrated across acquisition phases and programs. The goals of SBA are to:[35]

- Substantially reduce the time, resources, and risk associated with the entire acquisition process;
- Increase the quality, military worth and supportability of fielded systems while reducing total ownership costs throughout the total life cycle; and
- Enable Integrated Product and Process Development (IPPD) across the entire acquisition life cycle.

SBA enables continuous development and assessment of JSF effectiveness, supportability and affordability throughout the system life. It provides synthetic environments—for both operational effectiveness and logistics—where warfighters, government engineers and industry can jointly resolve acquisition issues throughout the acquisition spectrum:[36]

- In requirements analysis, through early investigation of numerous alternative concepts;
- In design and testing, through more efficient, robust design, test, and evaluation; and
- In training, through more robust, more cost effective maintenance and operational training.

As an example, the JSF Program is using the Joint Logistics Modeling Environment (JLME) and the Joint Synthetic Battlespace (JSB) to define operational effectiveness and supportability requirements for the JORD. JSF is using the JLME to purposefully plan the support concept for the JSF. JLME enables optimization of inherent sortie generation capabilities, logistics footprint, and operations and support costs. Using SBA allows assessment of a greater magnitude of potential concepts.

The goals of modeling and simulation within the JSF Program are as follows:[37]

- Provide analytic underpinnings for warfighter and senior management decisions through joint cooperative analysis. An efficient data collection and information management system must be maintained to support planning, executing and reporting the results from simulation activities and to ensure traceability to DoD and JSF Program guidelines.
- Immerse prototype JSF concepts into realistic synthetic environments to support early operational employment and support concept development and systems assessments. Virtual simulations must allow FPT pilots to participate in a common warfare environment consisting of theater scenarios with C4ISR/SoS architectures that support investigation of mission level effectiveness/performance, interoperability, pilot-vehicle interface and operational employment concept questions.
- Provide phased affordable implementation of the JSB to support analysis and RDT&E with capacity to evolve into a robust training environment. Through strategic alliances with other DoD organizations, JSF will develop a virtual JSF simulator design and an environment that will support distributed mission testing and training for the remainder of the weapon system life cycle.
- Incorporate a streamlined product life cycle for simulation activities. This is based on the principle of "build a little, test a little" to promote concentration and conservation of resources as the program advances into distributed simulation environments and live range testing.

JSF is providing government accredited dynamic operational and logistics synthetic environments in which the WSCs can assess the performance of their JSF aircraft against the Joint Model Specification

(JMS). In fact, SBA enables the use of JMS by capturing warfighter and threat tactics, techniques and procedures in realistic operational and logistics scenarios.

SBA provides a robust, dynamic threat and target environment for virtual testing of the JSF weapon system, enhances warfighter capability and controls cost, augmenting flight test by exposing the design to more robust (but less realistic) situations earlier and continuously through the development process.

5.2.5 Mission-Level Modeling & Simulation

Mission-level simulation is one of the keys to verifying the feasibility and reducing the risk of a single-seat strike aircraft to meet all of the participating services' requirements. During the first three years of CDP, JSF conducted numerous major mission-level modeling & simulation (M&S) events, including the seven VSWE exercises, as shown in Table 18.

Table 18: Major CDP Mission-Level M&S Events[38, 39,40,41]

Date	Event
March 97	Interdiction Mission Planning FPT @ NAS Pax River
July 97	Air-to-Air Mission Planning FPT (Air-To-Air Tactics) @ WPAFB
	Close Air Support Mission Planning FPT @ NAS Pax River
October 97	Mission Planning FPT @ Lockheed Martin
	Full Mission Simulation (VSWE Demonstration) @ Boeing
November 97	Mission Planning FPT @ Boeing
	Air-to-Air: JOUST (Real-time, pilot in the loop) @ DRA Farnborough, UK
December 97	Full Mission Simulation (VSWE Demonstration) @ Lockheed Martin
April 98	Air-to-Air: JOUST @ DRA Farnborough, UK
May 98	VSWE 1 (Choke Point Interdiction) @ NAS Pax River
June 98	MIL-AASPEM 1 (Defensive Counter Air) Simulation @ WPAFB
August 98	Full Mission Simulation @ Lockheed Martin
	Full Mission Simulation @ Boeing
	VSWE 2 (Unit Interdiction) @ WPAFB
September 98	Air-to-Air: JOUST @ DRA Farnborough, UK
November 98	VSWE 3 (Choke Point Interdiction) @ WPAFB
December 98	Full Mission Simulation @ Lockheed Martin
	MIL-AASPEM 2 (Self-Escort) Simulation @ WPAFB
February 99	JSF Imagery For Lethality (JIFL) @ NAWC China Lake
March 99	VSWE 5 (Unit Interdiction) @ NAS Pax River
April 99	VSWE 4 (Close Air Support) @ AFRL Mesa
May 99	Full Mission Simulation @ Boeing
August 99	VSWE 6 (JEFX 99 vs. TCT) @ NAS Pax River and WPAFB
September 99	MIL-AASPEM 3 (Coalition Counter Air/Self Escort) Simulation @ WPAFB
June 00	VSWE 7 @ Edwards AFB, NAS Pax River, and WPAFB
September 00	JEFX 00 (Force Level Exercise) @ Hurlburt Field and Nellis AFB

The Aircrew Systems Advisory Panel (ASAP), the warfighting element of the FPT, conducts the air-to-air and air-to-ground simulations. The Brawler, MIL-AASPEM and JOUST air-to-air models provided an existing capability to perform both digital and interactive simulation of air-to-air combat. However, air-to-ground mission modeling is more complicated due to additional factors such as terrain, background, weather, a wider variety of target signatures and a wider variety of threats. There are significant challenges in accurately modeling the performance of the various sensors used by the JSF and by the opposing forces under these conditions. Both constructive ("data in, data out") and virtual (real-time, piloted) simulations were determined to be necessary to support the necessary JSF requirements trade studies. Table 19 lists some key attributes that do and do not require piloted simulation for adequate insight into the effects of requirements trades.

Table 19: Key Attribute Relationships to Piloted Simulation[42]

Piloted Simulation Is…		
Not Required for:	**Desired for:**	**Required for:**
Sortie Generation Rate	Interoperability	Target Acquisition
Range	Delivery Accuracy	Target Identification
Payload	Low IR Signature	Low RCS
Hardening	Low Visual Signature	Situational Awareness
Redundancy	Speed	Countermeasures
Logistic Footprint	Weapon/Sensor Integration	All Weather/Night Capability
Weapons Carriage	Multi-Role Capability	Maneuverability
Low Acoustic Signature	Accurate Navigation	Mission Level Intelligence
	Route Planning	Pass/Receive Timely Information
	Mission Flexibility	Ability to Assess Effectiveness
		Emissions Control

Two existing models, EADSIM and Suppressor, provided a capability to perform constructive simulation of air-to-ground missions. Suppressor is highly regarded in its ability to realistically simulate the employment and interactions of opposing forces engaged in various types of combat in a closed loop fashion. A system known as the Simulation Warfare Environment Generator (SWEG) offered a capability to build virtual mission-level simulations. SWEG generates operational environments to support the interactions between "entities," i.e., friendly and hostile weapons systems, targets, etc.[43,44]

SWEG was selected to provide the "core" of the initial VSWE capability. During 1997, efforts were undertaken to model the Defense Planning Guidance (DPG) GCS in the SWEG to provide a consistent baseline that is representative of the likely 2010 threat environment, but insensitive to political changes in specific regions. This involved putting into the SWEG descriptions of the geographical scenario, threat systems and targets, multispectral imaging databases, a generic JSF, an initial threat Integrated Air Defense System (IADS), and mission routes as determined from the FPT mission planning exercises. Paradigm Simulation, Inc., Camber Corporation, and Photon Research Associates, Inc., were awarded contracts to create the imaging databases needed to simulate Close Air Support (CAS), Choke Point Interdiction (CPI), Unit Interdiction (UI), and Strategic Target Interdiction (STI) missions.

The "generic JSF" was developed to comply with JIRD requirements. Air vehicle performance characteristics were developed by the Air Vehicle Integration IPT in the JSF Systems Engineering Directorate in conjunction with the Design Analysis organization at the USAF Aeronautical Systems Center, Wright-Patterson Air Force Base, Ohio. This is a scaleable "rubber airplane" whose specific characteristics can be varied to support requirements trade studies. A generic RF signature database was provided by the JSF Survivability IPT, and the IR signature was developed using SPIRITS, the primary engineering model for IR signatures used by the services and industry. Bosque Technologies was awarded a contract to put the generic JSF into the SWEG, including the incorporation of certain inputs from the WSCs. In addition to this generic JSF, each WSC will have a "virtual prototype" of their PWSC that can be operated within the VSWE.[45] In 1999, work was begun on developing a generic JSF that can be released to the JSF international partners.

The VSWE, in conjunction with cost estimates, is used to perform cost/capability tradeoffs involving mission-level Measures of Effectiveness (MOEs) and Measures of Performance (MOPs). The VSWE allows pilots to "fly" through a hostile IADS and assess tactics, investigate capabilities, and vary them to obtain desired results. VSWE allows modification of the concept of operations to be assessed as a "non-materiel solution" to shortfalls that are identified, rather than changing the weapons system design to a more expensive hardware solution. Contractors are using the VSWE extensively to evolve their cockpit designs, while the government is evaluating the generic JSF in the VSWE to support higher level trades, including on-board/off-board information issues. A key challenge is to update cost estimates as quickly as

performance. The cost impact should ideally be presented up-front whenever any new concept or capability trade is being evaluated. Otherwise there will be a natural tendency to select the higher-capability design option, and when the cost implications show up later it could be too late to influence the decision.[46, 47]

While SWEG provides essential virtual simulation capability, there are certain features of the Suppressor model that are not supported by SWEG. JSF has therefore transitioned to a new Joint Interim Mission Model (JIMM), which combines the best features of both SWEG and Suppressor, in a virtual simulation format.[48] JIMM will serve as a prototype for the DoD next-generation mission model (NGMM), and can be used to conduct both constructive and virtual analysis, man- or hardware-in-the-loop testing, and to assess flight test and open-air range applications. JIMM was completed in January 1999 and was first actively used as part of VSWE 6.[49] A summary of each of the major government mission planning FPT and VSWE events is given below:

- The first mission planning FPT, held 16-21 March 1997 at the Air Combat Environment Test & Evaluation Facility (ACETEF – discussed in Section 7.2.1) at Naval Air Station (NAS) Patuxent River, was focused on interdiction missions, specifically, UI (an armored unit moving or stopped), INT (a roadway bridge or mobile SAM), STI (a bunker), and CAS (a moving tank column or other armored unit). This FPT was conducted using the mission planning system and Powerscene to provide stimulus for round table discussion on how the mission would be conducted and what aircraft capabilities would be desired and needed. The mission planning and rehearsal systems proved to be very effective in allowing the warfighters to gain some early experience in how to employ the JSF.[50]

- The second mission planning FPT was held 21-24 July 1997 at Wright-Patterson AFB, Ohio. This air-to-air mission planning FPT was made up of the OAG members and the government and contractor Brawler air-to-air combat simulation analysts. The objectives were to review Brawler pilot logic and tactics, facilitate OAG/analyst interaction and develop JSF air-to-air tactics. Five scenarios were discussed: 2 v 6 (two JSF aircraft vs. six enemy aircraft) defensive counter air (DCA) engagements beyond visual range (BVR), 4 v 4 self escort (SE) BVR, and 2 v 2 within visual range for tail-on, head-on, and side (beam) encounters. The Rafale with a MICA IR/RF missile was used as the threat aircraft.[51]

- The third mission planning FPT was held the following week, 28 July – 1 August 1997, at the Manned Flight Simulation Facility at NAS Patuxent River, Maryland. This FPT concentrated on the close air support mission area. The objectives were to obtain warfighter operational employment concepts for mission scenarios and planned missions for constructive and virtual simulations and analyses, as well as to identify JSF critical mission requirements for CAS. Specific vignettes (scenarios) studied included: urban CAS (neutralizing a point defense system near a US embassy, delaying advancing tanks, and suppressing sniper fire during evacuation), night/high level threat (CAS operations in a relatively high threat arena, at night, with the target set being an area target of troops and artillery), IMC (instrument meteorological conditions to 25,000 ft, where the target set is a group of vehicles in a mechanized infantry battalion) and night moving target (night, IMC, attacking moving tanks and armored personnel carriers).[52]

- In addition to strike simulations, JSF also conducted several air combat simulations using the Man-In-the-Loop Air-to-Air System Performance and Evaluation Model (MIL-AASPEM). The first simulation (MIL-AASPEM 1) was held 1-12 June 1998 at the WPAFB Simulation Facility (SimAF). MIL-AASPEM 2 took place 1-4 December 1998 at SimAF, and MIL-AASPEM 3 on 13-24 September 1999. These simulations evaluated the ability of JSF to conduct air-to-air combat, specifically, DCA (MIL-AASPEM 1 and 3) and SE (MIL-AASPEM 2 and 3). MIL-AASPEM 3 evaluated JSF performance in a coalition environment.[53]

- VSWE 1 was held 11-22 May 1998 at ACETEF at Patuxent River. The focus of this ASAP was on three specific choke point interdiction missions within the Generic Composite Scenario: a bridge, a SEAD target (SA-10B), and a mobile or relocatable target. Three types of weapons were dropped by the JSF: JDAM, JSOW and Wind Corrected Munitions Dispensers (WCMD). The threat level varied against the target set to evaluate differences in tactics and capabilities of the JSF and its weapon load.[54]
- VSWE 2 was held 17-28 August 1998 at SimAF. The objective was to conduct real-time pilot-in-the-loop simulation of representative UI scenarios to study cost and performance trades associated with the ability to acquire the target, identify the target, evaluate situational awareness and evaluate mission planning. The ASAP also provided insight to the OAG to allow informed decisions regarding key operational requirements for the development of the JORD.[55]
- VSWE 3 was held in 19-21 November and 7-11 December 1998 at SimAF, and employed a choke point interdiction mission scenario. The primary goal of this mission scenario was to destroy a SAM site or moving time-critical target. SEAD threat laydown variations were addressed through different mission scenarios, as well as varying capabilities of electronic support measures, real-time mission planning, off-board networks, targeting infrared, and weapon types. This was the first VSWE event where coalition partners participated.[56]
- On 8-12 February 1999, China Lake hosted a demonstration of JSF Imagery For Lethality (JIFL), a Design of Experiments (DOE) to look at the utility of various forms of on-board and off-board imagery in helping the pilot locate and kill desired targets in typical JSF missions. For this first DOE, on-board imagery was limited to that generated by a high resolution SAR, while off-board images in the IR, SAR and EO spectrums were included, and UI and CAS missions were flown. The JIFL concluded that a combination of on-board and off-board imagery improved the pilots' ability to locate and designate targets, but the on-board SAR was used for actual target designation. The pilots also established their preference for pre-loaded imagery vice imagery that is sent to the JSF in flight. This enables JSF pilots to study the target enroute and minimizes the amount of bandwidth required by limiting the amount of imagery sent to the JSF to only those pixels required for mission execution.[57,58]
- As a result of some model integration issues, VSWE 5 execution actually preceded VSWE 4. VSWE 5 was held at the Patuxent River ACETEF facility from 22 March to 9 April 1999, and focused on the UI mission area, evaluating the ability to locate and destroy moving armored vehicles, SAM sites and refueling depots, with WCMD, JDAM, or JSOW. Again, various capabilities of on-board and off-board sensors were evaluated for their contribution to lethality, as well as various levels of C4ISR architecture capability and *a priori* mission planning. Off-board imagery and/or target coordinate information supplemented the study of notional avionics suites in its contribution to mission effectiveness.[59,60]
- VSWE 4 was then held at the Air Force Research Laboratory (AFRL) in Mesa, Arizona on 12-23 April 1999. This event focused on the Close Air Support (CAS) mission and addressed the value of C4I products in the cockpit. Of interest to the OAG was VSWE 4's demonstration of the command and control relationship between the JSF pilot and the Forward Air Controller (FAC). It addressed the issue of JSF weapon employment where the FAC does not have or is unable to maintain visual contact with the JSF. The event provided insight into the contribution of on-board avionics and off-board C4I to JSF mission effectiveness, facilitating the articulation and justification of requirements in the draft JSF ORD.[61,62]
- VSWE 6 was conducted from 28 August to 6 September 1999 in conjunction with the Joint Expeditionary Force Experiment (JEFX 99) to test real world connectivity, as well as the Combined Air Operations Center processes. This event examined command and control aspects of dynamic

re-tasking in combat missions in response to time critical targets and operations in a multi-national environment. There were four JSF virtual cockpits participating in JEFX 99 – two at SimAF and two at the Manned Flight Simulation Facility – with both sites connected to the JEFX 99 wide-area distributed simulation network. Virtual JSFs flew 8-10 air-to-ground sorties per day, attacking high-value targets, including mobile and stationary SAM sites and other time-critical targets. The JSF aircraft were able to receive threat alerts and targeting data directly into the cockpit from numerous participating off-board systems, regardless of whether they were live, virtual or constructive sensors. This off-board information augmented and cued the JSFs' own on-board systems to help the JSF pilots find, fix, track, target and execute its designated objective. As mentioned above, this was also the first use of JIMM.[63,64,65]

Through 1998 and 1999, extensive increases in capability were introduced at each VSWE. Additional capabilities to model the environment, cockpit, weapons, and off-board sensors, and system of systems interactions, were added, so that most of the primary weapons being considered for JSF can be employed in the simulation.[66]

Six VSWE events were conducted through 1999 to help shape the JSF ORD. VSWEs are now expected to evolve into a T&E analysis tool to support the EMD phase of the JSF Program, and ultimately into a training/mission rehearsal tool for operational JSF pilots.[67] With the signing of the JORD, the focus of these events has now changed from evaluating operational concepts to developing a virtual environment in which the winning contractor will be required to exercise his "product." In essence, VSWE 7 was a risk mitigation exercise to support the EMD MS&A end state for the JSF Program as established by the JSFPO.[68]

VSWE 7 was held in June of 2000, and involved elements located at Edwards AFB, Wright Paterson AFB and at NAS Patuxent River. This event marked the first time that these widely separated elements had been joined in a virtual, interactive environment. It provided complimentary virtual analysis in support of an integrated JSF virtual and constructive analysis plan, and as with previous VSWEs, it provided the program with the "expert" opinions of operational multi-service pilots of the utility of new technologies that could be incorporated into the JSF. [69]

The objectives of VSWE 7 were to conduct real-time, pilot-in-the-loop simulations using the widely dispersed facilities of the three bases, and to evaluate performance trades associated with various JSF attributes and issues. Specifically, the functional objectives investigated and evaluated were the following: target acquisition, target identification, situational awareness, mission planning / rerouting, and the ability to pass and receive timely information. The use of geographically distributed "players" allowed for the analysis of the feasibility and utility of using such an approach to the virtual war-fighting environment. Since this was the first attempt at such a distributed virtual exercise, several problems were encountered (and overcome), especially in the area of system security. [70]

With VSWE 7, the focus of the VSWE events switched from evaluation of operational requirements to the development of a virtual environment, the Simulated Warfare Collaborative Environment (SWCE), in which the winning contractor will exercise his virtual aircraft. [71]

Another major simulation event was the Joint Expeditionary Force Experiment (JEFX) 00. Here, JSF Virtual Simulators (JVS) were to demonstrate JSF capabilities in a force level exercise. The simulations occurred at Hurlburt Field and Nellis AFB and concluded on 15 September 2000. The Chief of Staff of the Air Force and the ACC commander were briefed on JSF's participation and role during their visit to Hurlburt AFB. The event concluded with the JVSs flying numerous missions as part of strike packages with F-22s, F-16s, AV-8Bs and interactions with various elements of C4I net – JSTARS, AWACS, etc. [72]

Virtual air-to-air and air-to-surface simulations were also conducted for Turkey at NAS Patuxent River on 18-29 September. The events demonstrated the increased effectiveness and situational awareness of the JSF versus legacy aircraft.[73]

The JSF Modeling and Simulation Support Plan (version 5.2) was signed on 8 November 2000 to support the EMD CFI release.

5.2.6 Operational Employment and Support Concept Document (OESCD)

The mission planning exercises mentioned above provided insight into the initial tactics development and concept of operations. This insight was captured in the first draft JSF OESCD, released in August 1997. The OESCD is similar to a traditional Concept of Operations (CONOPS), with an increased emphasis on how the weapons system in question will be supported.[74]

5.2.7 Maintainer in the Loop/Maintenance System Advisory Panel (MxITL/MSAP)

Maintainer in the Loop (MxITL) is a joint initiative begun in 1997 by the JSF Requirements and Supportability Directorates. MxITL is a process to improve JSF supportability through the expertise of senior logisticians and maintenance technicians from the four participating services. Maintenance actions will be performed in physical and simulated environments, and the data used to influence JSF requirements, weapons system designs, and support/training concepts. The role of MxITL will mature in parallel with the JSF Program, providing the foundation for the development of advanced training systems during EMD, and ultimately a virtual maintenance environment for the operational JSF. This will be used for maintenance training, including "just-in-time" training and rehearsal of impending maintenance actions.[75]

Maintenance simulation is part of the MxITL process. At the level of the individual weapons system, maintenance simulation primarily fits into the interactive digital simulation or virtual simulation categories (constructive simulation applies more to the campaign level, to model the logistics and support of large aggregates of weapons systems). The starting point for virtual maintenance is the substantial body of virtual manufacturing tools and expertise that already exists. The same tools that can be used to virtually assemble a digital model of an aircraft, can be used to "maintain" that same model: simulating remove/install operations, checking for interference and verifying fits and clearances, positioning service equipment, etc. After an initial $300,000 feasibility demonstration, maintenance simulation was funded with approximately $8M for FY97.[76] Following the replan efforts in May 1999 (described in Section 5.1.5), however, JSF discontinued the funding of MxITL.

The Maintenance Systems Advisory Panel (MSAP) provides the involvement of current, experienced logisticians and hands-on maintainers in the MxITL process. The MSAP is analogous to the ASAP, but for maintenance and support. They provide inputs to the JPO and the contractors, some of which have immediate influence on the evolving designs, while others provide information, clarification, and/or possible future design influence. The MSAP and the ASAP essentially constitute the maintenance and the warfighting elements, respectively, of the FPT.

The MSAP was formally launched at the JSF Training & Mission Planning FPT meeting in March 1997. Eighteen MSAP members, grade E-5 through E-9 (or UK equivalent), were introduced to the MxITL concept and given demonstrations of enabling simulation technologies by each of the WSCs. The propulsion prime contractors also participated. The MSAP then visited Pratt & Whitney in May 1997, resulting in detailed technical interaction between maintainers and propulsion system designers/developers.[*]

[*] This continues a process that was integral to the design of the basic F119 and F120 engines, from the start of their development in conjunction with the USAF Advanced Tactical Fighter (ATF) Program in 1983. Providing designers with an increased awareness of maintenance issues—through first-hand interaction such as visits to operational maintenance facilities—was a major thrust in the ATF engine program. Designers learned to reduce the complexity of commonly required maintenance actions; use captive fasteners; and minimize the number of different tools required. This resulted in large improvements over the prior generation of fighter engines (i.e., the early models of the F100).

The MSAP continued to visit the airframe and engine companies. WSC reviews were held semi-annually, in conjunction with FPT meetings. Primary emphasis was in the following areas:

- LO supportability
- Engine removal/installation
- Integrated Combat Turnaround (ICT)
- New technologies, including J/IST, MIRFS and other avionics areas, and Prognostics & Health Management (PHM) (described in Section 5.3)

Through the end of 1998, the MSAP team had conducted about a half-dozen meetings at each of the WSCs and two at P&W. By the end of 1999, a total of 19 meetings had been held (i.e. four more in 1999). These meetings have resulted in an excellent exchange of information between design engineers and fleet maintainers. The participation of maintainers as members of the WSC IPT process provides early insight and thereby early design influence. This insight into design issues has impacted PWSC design and continues to provide the WSCs with warfighter perspectives to logistics and maintenance environments from all services. Documentation of the exchange of information between the MSAP and the WSCs is captured in a database that is continually reviewed for resolution. By 2000, the MSAP was still providing the JSF program with information on an as-needed basis, but due to the initiation of source selection activities, was not actively engaged with the contractors.

5.2.8 COPT IV/Draft JORD/ORD

In support of the ORD development, several studies, in addition to the VSWE simulations, were conducted as part of COPT IV in 1999. These included the electronic support measures (ESM) and electronic attack/electronic protection (EA/EP) studies.

As mentioned above, the draft JORD was completed in April 1999, and by the end of the year, the final ORD was awaiting review by the JROC. As was shown in Table 16, the focus of the Draft JORD was supportability, system of systems and avionics trades, mission planning and training, and LCC. Each revision of the JIRD has also contained greater specificity. Table 20 shows the evolution of some selected requirements from the JIRD in 1995 through the unsigned JORD at the end of 1999. This is only a top-level comparison of performance characteristics, which cannot capture the subtle nuances of changes in mission profiles, etc. However, the fact that in several areas shown here the requirement was *reduced* shows that the CAIV process is working. The extensive modeling and simulation discussed above is critical to determine which requirements can be increased and which decreased for the most cost effective weapon system.

The URF cost goals remained the same as had originally been established in 1994, with the exception of the lower range (threshold) for CTOL being changed to TBD, and an objective of $28M. This was as a result of the latest calculations of software and software integration cost estimates. Another, smaller, contributor was an increase in instantaneous gravity forces from 8*g* to 9*g* for CTOL. This was determined to be necessary to avoid the threat from predicted advanced surface-to-air missiles in future conflicts.[77]

Table 20: Evolution of Selected JSF Requirements, 1995-1999 [78,79,80,81,82]

(b)(4)

[redacted]

In the Draft JORD, extensive additions to the "Logistics and Readiness" section detail thresholds and objectives for each variant: logistics footprint, sortie generation rate, mean flight hours between failures, mean time to repair, mean flight hours between removal, and mean flight hours between maintenance events, as well as fault detection rates, fault isolation rate, mean flight hours between false alarms, and others. The Navy and Marines had desired the option of two seat versions in JIRD II and III, but the Draft JORD eliminated the requirement for a second seat for the Navy (an operational "missionized seat" in JIRD II and a training version in JIRD III) altogether; for the USMC, "An option for a two-seat STOVL training variant will be determined once the cost (EMD and LCC) of operating a two-seat trainer versus the risk of single-seat initial training are fully understood."[83] For the ORD, this was modified to "STOVL maintains the option for a two-seat variant."[84]

The inclusion of a gun on the JSF variants also underwent a number of changes over the evolution of the JIRD/JORD. Not mentioned in the initial JIRD, JIRD II states, "The CV and CTOL variant will provide the design space for an advanced internal gun. Options for carriage of an advanced gun on the STOVL variant are desired; internal carriage is preferred."[85,86] JIRD III cites "an internal advanced gun optimized for air-to-ground with a secondary role of air-to-air," for CTOL, and "a missionized advanced gun that can be removed and installed and have no impact to aircraft handling qualities or desired minimum bringback once removed," for STOVL. An "internal or podded missionized advanced gun" is stated as a desired objective for CV.[87] The Draft JORD restates these requirements with the addition of probability of kill (Pk) thresholds of [redacted] and objectives against lightly skinned armored vehicles at [redacted] feet slant range.[88] In the ORD, the internal gun (not required to be "advanced") is stated as a threshold for CTOL and a "missionized gun" for STOVL; for CV, the design "must preserve space and provisions for either an internal or missionized gun." The objective for CV was to have an internal or missionized gun and for STOVL to have a removable internal gun; an objective Pk of [redacted] with a slant range of [redacted] ft was also specified for all variants.[89]

Extensive additions to the weapons carriage requirements were also made during the JIRD/ORD process. While the initial JIRD just referred to 1000 lb and 2000 lb class weapons and AIM-120s, JIRD II identifies fourteen 1000 lb class and four 2000 lb air-to-ground weapons to be carried internally and "To the maximum extent practical, JSF should carry and employ all DOD current and POM'd [i.e. future budgeted] TACAIR ordnance externally."[90] JIRD III lists desired minimum and objective weapons for each service variants (including UK) for internal and external carriage: the desired minimum lists eight US internal air-to-ground weapons, and "all 1000 lb class weapons"[91] plus five additional variants of the 2000 lb weapons for desired objectives. The desired minimum for external carriage added nine additional US air-to-ground weapons plus external tanks; the desired objective again advocated all DoD current and currently budgeted weapons. The ORD lists a total of 17 internal weapons for the air-to-ground threshold, and lists 16 additional US air-to-ground weapons/variants plus internal fuel tanks and reconnaissance packages for the objective, as well as the AIM-9X *internally* and up to *six* AIM-120Cs for CV. For US external carriage, 42 various items are listed for the threshold, including fuel tanks, practice rounds, travel pods, rockets, etc; 28 additional items/variants are stated as the objective. A prioritized list of external weapons was also provided, which showed that about half of these were planned for qualification during EMD.[92,93,94,95,96]

The Draft JORD and the final ORD also identify Key Performance Parameters (KPPs), defined as "a capability or characteristic so significant, that failure to meet the threshold can be cause for the concept of the system selection to be reevaluated, or the program to be reassessed or terminated."[97] Whereas 14 parameters were listed as KPPs in the Draft JORD (see Table 21), only the following eight attributes were listed as KPPs in the ORD: interoperability, RF signature, combat radius, mission reliability, logistics footprint, sortie generation rates, CV recovery performance, STOVL mission performance. In August 1999, a Chief of the JCS Instruction (CJCSI 3170.1A) required future systems to ensure adequate information exchange between services. The final ORD was originally planned for review by the Joint Requirements Board (JRB) and Joint Requirements Oversight Council (JROC) in December 1999, but this slipped into early 2000 in order to resolve certain last minute issues (e.g., CTOL cost, 9*g* and interoperability). JSF was

originally expected to be "grandfathered" out of the JCS directive on interoperability, but once the JROC looked likely to slip, the ORD was modified in an attempt to comply. The JROC validated the ORD on 13 March 2000.[98,99]

Table 21: Draft JORD KPPs[100]

Key Performance Parameters	Variant(s)
Unit Recurring Flyaway Cost	All
Combat Radius	All
Mission Effectiveness	CTOL
Supportability Effectiveness	CTOL/CV
Deck Spot Factor	CV
Takeoff Performance	CV
Approach Speed	CV
Bringback Recovery Performance	CV
Acquire The Target	CV/STOVL
Internal Carriage Capability	CV/STOVL
RF Signature	CV/STOVL
Logistics Footprint	STOVL
Short Takeoff	STOVL
Vertical Landing	STOVL

5.2.9 JSF Model Specification (JMS)

Procurement of a new weapon system includes requirements that the system must fulfill. As discussed above, the ORD lists these fundamental requirements to be achieved by the new weapon system. Concurrent with the ORD's development, the engineering context of these fundamental requirements must be decomposed into the specific engineering constraints that define the performance of the weapon system.

The Joint Strike Fighter Model Specification (JMS) Document serves this purpose, by defining a performance based set of measurable functional attributes that the JSF weapon system must fulfill. The WSCs use the requirements listed in the JMS to allocate and derive the full design drivers for shaping the physical and functional attributes of their JSF PWSC designs.

The JSFPO has applied the initiatives of DoD's Acquisition Reform throughout the JMS development. The JMS requirements listed are performance-based, in that they are not "how-to" directions imposed by the government onto the WSCs for designing the aircraft. Instead, the requirements provide sufficient information to define the full context of the fundamental requirements stated in the ORD, without overly constraining the WSCs from optimizing the system to meet performance, cost, and schedule limitations, thereby allowing the WSCs to propose "best value" systems.

The JMS main document consists primarily of two sections. The main section (Section 3) contains the requirements, which are developed by the government with assistance from the WSCs. Each requirement is traceable to the fundamental requirements stated in the ORD. Section 4, which is proposed by the contractors in response to the CFI leading to Milestone II, contains the incremental verifications that the contractor will conduct during EMD to meet the Section 3 requirements. In addition to the main body of the JMS, there are a number of appendices to the document. These JMS appendices provide definitions of key requirement terms, ground rules and assumptions for the calculation of performance attributes, descriptions of operational interfaces, descriptions of mission scenarios, and descriptions of the natural and induced environments for JSF.

The JMS document was updated over several revision cycles, in preparation for its final release to the WSCs in November 2000. For each revision effort, the SE Directorate checked each of the JMS statements

for completeness and clarity, as well as for full engineering and programmatic justification. While the JMS must be substantial enough to bound the problems to be solved by the JSF weapon system, the requirements must be limited in scope to enable engineering flexibility by the WSCs to optimize their designs. With these aims in mind, the JSFPO obtained and evaluated revision suggestions from all SE IPTs and other JSFPO Directorates, and revised the JMS document using the final judgment of the SE Director.

Using a managerial process within the JSFPO called the Systems Engineering Review Board (SERB), each of the JMS requirements was assigned to an "owner": a government engineer responsible for assessing, revising, and justifying the specifications linked to his or her technical area. Without clear determination of "owners", some requirements could have been neglected by the collaborative assessment effort, while other specifications would be over analyzed by too many responsible parties. At the start of each revision cycle, the current JMS version was converted into a software-based "coordination file", which collates all revision suggestions from each of the owners. In addition, the coordination file would archive the final acceptance or denial resolutions of each suggestion, as determined by the SE Director. This process provides a means for all teams to have the opportunity to voice concerns and recommendations for the JMS revision, and to have those statements archived for future programmatic and historical analysis.

Each specification requirement must be justified for inclusion into the JMS document. One reason justifications are necessary is to actively counter "requirements creep", the phenomena of superfluous requirements over-constraining the design space. A second reason for requirement justifications is to prepare the JSFPO for working with, and explaining the documented requirements. When a requirement owner has taken the effort to write and revise the requirement, research its substantiation, and has successfully defended its inclusion through the JSFPO's approval process, he or she has become an "expert" of that requirement. The owner then is in a well informed position to evaluate the WSCs' technical designs against the requirement, and to be able to explain the requirements when questioned by the WSCs.

The development of the JMS was a joint Government/WSC activity. Since the inception of the JMS development and revision process, representatives of the WSCs participated in joint sessions with the government. During each of the JMS development reviews, the WSCs were encouraged to voice concerns and opinions of the JMS requirements, as well as to request appropriate language that enables the WSCs to optimize their designs.

5.3 Technology Maturation

This section describes all efforts that are concerned with maturing technologies to low risk prior to EMD entry. Most of the major, multi-year demonstration programs introduced in the preceding chapters have continued (although some were terminated), and a few new initiatives have started. Since the JPO reorganization at the beginning of CDP, these efforts have become distributed among several Directorates. In addition to Systems Engineering (which includes the former TM Directorate), the Supportability Directorate, the JAST Directorate, and the Propulsion management team are all responsible for Tech Mat efforts. Some Tech Mat efforts are also being performed under the WSC and propulsion system contracts.

5.3.1 Continuing Technology Maturation Demonstration Programs

Several major, multi-year Tech Mat efforts were introduced in the previous chapter. Developments in these programs in 1997-2000 are described briefly below. These are updates only; for descriptions of these projects see Section 4.3.2.

JSF Integrated Subsystems Technology (J/IST): Critical Design Reviews for the J/IST demonstration hardware were completed by July 1997, with the exception of the engine related hardware and modifications, which was completed in June 1998. During 1997 and 1998, hardware fabrication and component level tests and demonstrations were conducted. J/IST is demonstrating the technologies and integration concepts for a highly integrated subsystems suite with revolutionary improvements in weight,

efficiency, and parts count compared to traditional subsystems. It is important to remember, however, that J/IST is not designing or developing the subsystems suite for the JSF; it is the WSC's responsibility to design the specific subsystems suites for their JSF weapon system concepts.

The J/IST architecture is being validated by a series of Tech Mat activities. Of the four major integrated demonstrations discussed in Section 4.3.2, all but one has been successfully completed: T/EMM development tests were conducted in 1998, including validation of all operating modes, but the final T/EMM system test is planned for early 2000. Tests of two T/EMM turbomachinery cores were completed in April 1999, including 51 hours of operation and 76 starts. Tests performed included: mechanical checkout, surge and turbine temperature margin, performance measurement and mode transitions. The tests validated core performance, and demonstrated the viability of the T/EMM design, including on and off-design operability, and emergency power mode capability, and provided risk reduction for T/EMM controls integration. The T/EMM system pneumatics and controls integration was also completed in June 1999. This validated the integrated operation of the T/EMM hardware with simulated engine and aircraft interfaces. It also tested the management unit, facility control computer, the simulators for the main engine, and power management and distribution (PMAD), thereby demonstrating the readiness of the test facility for integrated T/EMM system level tests. [101]

In December 1999, the J/IST program conducted a demonstration that linked the T/EMM high-speed starter/generator and the main engine starter/generator. This demonstration showed that a high-speed machine running as a generator could produce sufficient electrical power to start the JSF engine by driving the engine starter/generator in the starter mode. The tests also proved the viability of the two devices working as generators to provide power to a triplex electrical power system with electric flight control actuators. These demonstrations were conducted with a Honeywell (formerly AlliedSignal) T/EMM starter/generator as a power source, and a Hamilton Sundstrand engine starter/generator to simulate engine starts, steady state loading, and transient loading. The tests were successfully conducted, demonstrating an acceptable voltage ripple and power quality.[102]

The final J/IST demonstration will consist of the integration of the T/EMM system with an actual F119 engine in early 2000. The starter/generator tests were the final demonstrations required to reduce the risk of initiating testing with a P&W F119 engine to "Low." Major components include an engine with fan duct heat exchangers, the T/EMM, and a switched reluctance starter/generator. Pratt & Whitney, Boeing-St Louis, AlliedSignal Aerospace, and Northrop Grumman are jointly responsible for the execution of this demonstration, which will be complete in spring 2000. Shown in Figure 41, below, is a model of the test F119 engine case, from the compressor through the exhaust case. The forward manifold is for the heat exchangers. The T/EMM is shown below and slightly forward of the engine case.

(b)(4)

Figure 41: J/IST T/EMM-F119 Engine Integration

During May 2000, a full-scale demonstration of the T/EMM was begun at Pratt & Whitney's West Palm Beach test facility. All of the planned mission profiles were successfully completed. The engine timed start from T/EMM-off to engine-on was 63.1 seconds. The engine with the T/EMM successfully demonstrated itself in all modes and operations, thus clearing the path towards first flight of the J/IST AFTI/F-16.

(b)(4)

Figure 42: T/EMM Engine Integration Demonstration at P&W West Palm Beach

Modifications to the Advanced Fighter Technology Integration (AFTI) F-16 (shown below) were completed in the summer of 2000. The aircraft had all of its current hydraulic flight control actuators replaced with newly designed electrohydrostatic actuators (EHAs). A new 270 volt DC electrical power system to activate the EHAs was also installed. The primary objective of this demonstration was to reduce the risk associated with transitioning new flight control and electrical power system technologies into the JSF PWSC designs. First flight of the AFTI F-16 was originally planned for January 1999, but actually occurred on 24 October 2000 (the same day as the X-35A first flight). The actuators were installed and tested in June 2000, followed by integration and testing of the flight control system hardware. Delays were primarily caused by technical problems with development of the EHA system architecture: failures during endurance tests for major components led to redesigns of some of the actuator components, including the pumps. [103]

Modifications to the AFTI aircraft include replacing hydraulic actuators for the elevators, rudder and flaperons with the new EHAs. A 270 volt DC generator, emergency power unit and silver-zinc emergency battery were installed to power the EHAs.[104] Four actuators operate the elevator and wing-mounted flaperons (see Figure 43), and a single, smaller EHA actuates the rudder. Each EHA has a dual, tandem actuator with two isolated, integral pumps and motors. Although the EHAs are larger than and weigh nearly twice as much as the F-16's original hydraulic actuators, the system reduces overall weight because hydraulic pumps, gearboxes, plumbing, and fluid reservoirs can be nearly eliminated. [105]

(b)(4) [redacted]

Figure 43: Horizontal Tail/Flaperon EHA

The AFTI flew with only the EHAs for flight control, but retained hydraulic system "B" to operate the landing gear, leading-edge flaps and speed brakes. Lockheed Martin conducted months of ground testing before the first flight to check system functionality and confirm operation of the flight controls, including fault tolerance, electromagnetic interference, vibration tests and calibration. [106] The high power EHA performance demonstrations were completed on 24 March 1999. The EHA/AIT Integration Demonstration was completed on 4 June 1999. Two months of flight tests demonstrated the systems under aerodynamic loads. The tests also allowed the engineers to validate the computer models of the system.

Figure 44: The J/IST AFTI/F-16 In Flight.

In addition to the AFTI F-16 flight demonstration, a ground demonstration of the J/IST electric power and flight actuation architecture was conducted. Northrop Grumman coordinated critical demonstrations that verified the integration of a 270 VDC electrical power system, high horsepower EHAs built by Moog, Inc., and two switched reluctance starter/generators built by Sundstrand Corporation and AlliedSignal Aerospace. In March 1999, EHA tests were conducted that demonstrated the necessary performance to meet their stated performance requirements within the weight and volume constraints. In June 1999, JSF completed the EHA/advanced integration test demonstration. These tests verified multi-channel integration, advanced integration test integration, realistic duty cycles and thermal characteristics. The demonstration showed that the EHAs were capable of high power (over 50 hp) and high-speed actuation (over 5 Hz). The EHAs also demonstrated adequate stiffness, fault tolerance and supportability. In December 1999, a high power actuation integration demonstration was conducted. These tests used a Moog triplex high power EHA, with a three bus PMAD architecture. Tests with dynamic loads demonstrated normal operation, EHA

and PMAD fault tolerance testing, 50 ms emergency bus switching, and acceptable EMI measurements. Regenerative power was also observed. These tests reduced the PMAD risk to "Low."[107]

Figure 45: Northrop-Grumman PMAD Ground Demonstration Model.

Multi-Function Integrated Radio Frequency Systems (MIRFS): Both MIRFS contractors—Northrop Grumman Electronic Sensor Systems Division (formerly Westinghouse) and Raytheon (formerly Hughes)—had successful Critical Design Reviews (CDRs) during 1997. As in the case of J/IST (above), MIRFS is not designing the RF system for the JSF. The objectives of the MIRFS program are to integrate and demonstrate (including flight test) two multi-function nose aperture concepts. The WSCs are responsible for additional concept refinement, forebody integration and testing (RCS and antenna patterns), and integration with ISS (below), as well as electronic warfare (EW) and communication/navigation/identification (CNI) aperture design.

Integrated Sensor System (ISS): To date, ISS has been funded jointly by JSF and the Air Force Wright Laboratories (WL), and managed from WL. If further maturation in this area is determined to be necessary, JSF will evaluate and coordinate any future funding efforts.

Integrated Core Processing (ICP): Phase I of the ICP effort—defining the attributes of the JSF open systems architecture—was completed during 1997. The WSCs have begun Phase II, which concentrates on the implementation and demonstration of specific ICP concepts. Technology demonstrations are being conducted in the areas of fusion/interface with the pilot/vehicle interface (PVI), sensors, stores management, and integration with the radar.

Virtual Manufacturing (VM)/Simulation Assessment Validation Environments (SAVE): In 1997-98, the SAVE architecture was redesigned to more efficiently handle the M&S tools for a seamless virtual environment. The SAVE infrastructure was modified to incorporate a Common Object Request Broker Architecture (CORBA)-based shared Data Model and Workflow Manager and a commercial "Electronic Collaborative Design Notebook" to integrate a suite of six commercial manufacturing tools: schedule, factory, assembly, dimensional variability, cost, and risk simulations. Additionally, the tool vendors worked closely with the SAVE engineers and the tools were modified to be "SAVE Compliant." In the future, other tools may be added by developing simple SAVE-compliant CORBA "wrappers."

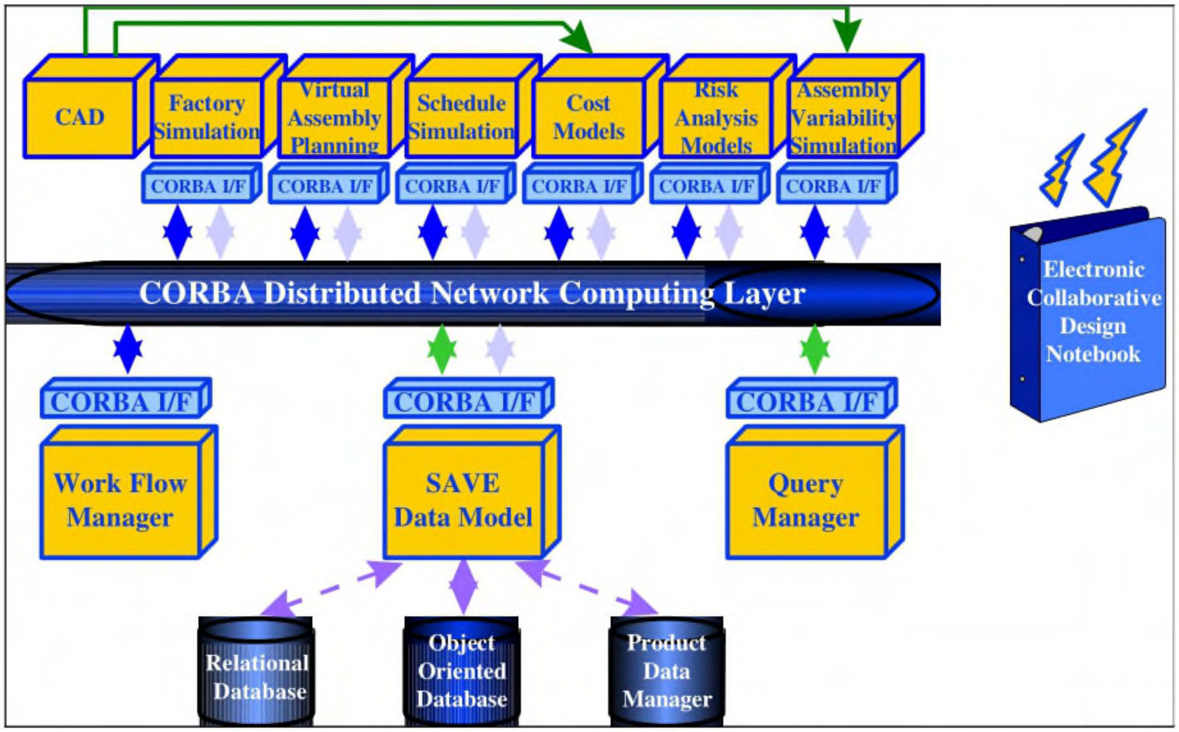

Figure 46: SAVE Architecture

In July 1998, a redesign of the F-22 gunport was done using this interim SAVE environment. This demo accurately predicted the cost, schedule, and risk of products and processes during design. The simulation tools also identified and eliminated potential manufacturing problems long before actual production. The ergonomic simulations in SAVE were able to show that using the current assembly sequence, the operator would be unable to safely perform several of the assembly tasks. In addition, the SAVE tool system surfaced potential bottlenecks in the production run for the new gunport assembly. These discoveries allow design engineers to rework the assembly sequence to correct the problem prior to full-scale production. The 1998 gunport demonstration improved process planning, reduced production bottleneck, and projected for JSF a $1.1M unit recurring flyaway and 2-3% Life Cycle Cost savings with full SAVE implementation. During 1999, SAVE conducted beta testing at the two JSF contractor sites. This gave the JSF development teams early hands-on experience with the SAVE integrated tools environment and resulted in excellent feedback to the SAVE development team. The final demonstration illustrated a redesign of the F-22 weapons bay doors to eliminate chafing, validating the use of the system on a real-world problem. Commercialization plans to make the SAVE tools integration approach an industry standard were presented to and approved by the two SAVE Program Advisory Boards in July 1999. Both the Society of Manufacturing Engineers (SME) and the Object Management Group (OMG) are interested in pursuing the long-term ownership and maintenance of the SAVE architectural approach and standard data model. Efforts continued in 2000 with government, industry, and vendor organizations working through the standardization process with SME/OMG.

Figure 47: Attaching F-22 Weapons Bay Door in a Virtual Manufacturing Demonstration

JSF Manufacturing Demonstration (JMD): The Raytheon-led JMD team developed, refined and demonstrated lean practices and processes and integrated design/cost database and tools that can aid the JSF community in significantly reducing JSF LCC. JMD developed an Integrated Product and Process Development (IPPD) process that emphasized CAIV; defined and documented key lean practices/processes developed for the IPPD environment; and integrated design and cost data and tools to make the data available to the IPT in near-real time. In 1996, the JMD team performed design trades to reduce the cost of the DARPA-funded High Density Microwave Packaging (HDMP) tile array. The mini-demonstration, held in January 1997, reduced the cost of the tile transmit/receive electronic modules by 19.3%. The methodology also showed a 60% reduction in tradeoff cycle time and a 27% reduction in tradeoff labor hours. Applying the same methodology to a more complex subarray during the initial phase of the full demonstration in 1997, the results were equally impressive. Although the JMD team was well on the way to reaching its 20% cost reduction goal on the HDMP tile subarray for the full demonstration, the program was descoped in December 1997 due to competing funding priorities. As part of the JMD program, however, the team had documented lean practices and processes, as well as integrated tools that the program was developing. The JMD documents and videos were delivered in spring 1998 for JSF community use and in 1999 a sanitized version of these documents were approved for open distribution.

JSF Manufacturing Capability Assessment and Toolset (JMCATS): The GRC JMCATS contract was completed in June 1998, with successful demonstrations in the areas of propulsion, composite structures and electronics assembly. In December 1998, the JMCATS tool and approach was again utilized to successfully identify and compare manufacturing and process risk assessments in the redesign of a helicopter fuselage.

Composite Affordability Initiative (CAI): The CAI program is comprised of three separate efforts. CAI Fast Track was a JSF-sponsored contract with Scaled Composites Inc. (SCI) to design a totally composite aircraft with an option to test a flight demonstrator. In 1997, the program developed a number of alternative designs for composite aircraft that were reviewed by both WSCs and the JPO. Upon completion of the final design review in January 1998, the government and two WSCs agreed that the proposed designs were beneficial and that the SCI ideas and features could be transferred to the JSF PWSC design, but that further development and flight testing was not necessary.

The CAI Transition Technology program involves contracts with both WSCs. The Office of Naval Research (ONR) has funded the effort to explore high-risk, high-payoff composite solutions, including transitional ideas from the SCI contract effort. Ultimately these efforts, if successful, would transition into the PWSC design for EMD. The Boeing and Lockheed Martin efforts are geared towards maturing and

implementing technologies for the PWSC aircraft. During 1997, both programs screened technologies and conceptual designs of components. During 1998, more detailed designs of structural components occurred. In addition, coupon and element testing was conducted. During 1999, both contractors further refined their design and process concepts and fabricated full-scale component demonstrations (with tooling) for process analysis and structural/ballistic testing. Data was collected on demonstrator concepts and validated by the WSCs: weight, cost, schedule, etc. to document affordability goals and risk reduction for successful transition to WSCs. Both teams also continued with further refined risk reduction/testing efforts in support of their WSC concepts. In 2000 both teams worked with the CAI Team to define a follow-on Phase III Transition effort to design and demonstrate a large structural aircraft section applicable to their PWSC. The winning JSF contractor will 50-50 cost share the demonstration to begin in 2001 in parallel with the EMD efforts.

An example of the advantages of the CAI Technology Transition program was demonstrated by Lockheed Martin. Lockheed Martin developed 3-D woven composite preformed structural parts for its PWSC design, demonstrating an improved ability of composites to efficiently carry out-of-plane structural loads, as well as reduced weight and cost. The application of 3-D preforms to the JSF inlet duct reduces the cost of the duct by at least $200,000 and saves more than 80 pounds of weight. The engine inlet of Lockheed Martin's JSF production design consists of a seamless fiber-placed duct stiffened with 3-D woven composite preforms. The use of these preforms for stiffening eliminates 95% of fasteners through the duct. Fewer fasteners improves aerodynamic and signature performance, eliminates fuel leak paths and simplifies manufacturing assembly.

The CAI Pervasive Technology Program is a long-term project to develop the tools and technologies necessary to enable aircraft designers to confidently design an all composite airframe utilizing revolutionary design and manufacturing concepts with breakthrough reductions in cost and weight. Both JSF contractors have been participating in this effort since 1997. In 1999, the WSCs assisted in finalizing medium & high risk composite designs and fabricating demonstration test articles. These articles involved a wing box, forward fuselage and keel duct assembly. In 2000, the WSCs assisted in the design and fabrication of a vertical tail and cockpit tub. These articles have application to JSF and are being used to demonstrate the analytical tools and manufacturing processes developed earlier in the program. They also participated in a number of composite material efforts, development and demonstration of analysis tools, and in beta testing a CAI cost model.

Joint Paintless Aircraft Program (JPAP): As discussed in Section 4.3.2, JPAP has demonstrated that appliqué technology is feasible for supersonic aircraft. As anticipated, JPAP appliqués have achieved a 90% reduction in hazardous materials as compared to painting, and it permits concurrent maintenance. Appliqués are also 50% more durable than paint and they permit weight consistency between aircraft of the same make, model, and load, whereas the touch-up layers of conventional paint can add hundreds of pounds to the weight of a fighter.[108] Both JSF WSCs intend to use appliqué rather than paint on their production JSFs.

In June 1997, Boeing received a six-month add-on contract to study maritime corrosion issues. In August 1997, more than 90% of the surface skin of a second Boeing F/A-18B test aircraft was covered with appliqué material (see Figure 48). Dedicated maneuvering loads and supersonic performance test flights were completed. Additional flight time and environmental exposure was gained through chase, test project, and training flights with the test aircraft. In addition to flights at NAWCAD Patuxent River, the test aircraft was taken on two short detachments to the aircraft carriers USS Enterprise (CVN-65) and USS Kennedy (CV-67) for catapult takeoffs and arrested landings and exposure to shipboard environments. Total time accumulated during this test phase was 398 flight hours (260 flights). Both the partially- and fully-covered F/A-18s accumulated most of their flight hours supporting other programs as chase aircraft, targets, etc.

Figure 48: F/A-18B With Complete Appliqué Covering

The Boeing/3M appliqué materials, adhesives, and edge sealers performed well during the flight tests and verified that the concept of an appliqué coating replacing the standard topcoat paint was feasible for a tactical supersonic military aircraft. The appliqué demonstrated improved supportability characteristics requiring less maintenance man-hours for support and repair and improved aircraft availability when compared to standard aircraft topcoat paint. Typical appliqué repairs were accomplished in less than a half-hour and repairs could be performed concurrently with other maintenance and did not require special environmental conditions or long cure times.

While JPAP is being conducted by Boeing (teamed with 3M), Lockheed Martin is conducting its own appliqué program, also teamed with 3M, under a contract with NIST and the Commerce Department. Lockheed Martin's appliqué program includes flight tests on S-3, F-16, and C-130 aircraft. An S-3, with appliqué coating on portions of the aft fuselage, completed a 5-week carrier deployment during mid-1997 to test the durability and effectiveness of the coating under maritime conditions. Three F-16s have been flown with appliqué applied to a tail panel, the upper fuselage and wing surfaces, and a centerline fuel tank, respectively. Subsonic and supersonic flight has been accomplished. A C-130E has been flight tested with 1,600 square feet of appliqué on the forward fuselage. As part of its CDP contract, in 1998 Lockheed Martin began preparations for a one year appliqué coupon flight test program on F/A-18 aircraft at Patuxent River. This program, which began in February 1999, has provided Lockheed Martin with insight into appliqué performance in a maritime environment. Lockheed Martin, like Boeing, is developing improved coating materials and procedures in parallel with its flight test activities.[109]

In late 2000, Lockheed covered an F-16 (shown in Figure 49) with approximately 1,300 ft^2 of appliqué made a series of successful test flights, attaining a top speed of Mach 1.8. This represents virtually the entire paintable external surface, including the fuselage in front of the inlet. [110]

Figure 49. Appliqués being applied to an F-16 aircraft.

The JPAP appliqué material development and flight test program has provided significant risk reduction and valuable lessons learned for potential use of appliqué technology on the JSF or other aircraft platforms. Due to the vast potential for cost and environmental savings with the appliqué technology, numerous studies and test programs have been initiated to evaluate replacing topcoat paint with appliqué materials on existing production aircraft and for many other applications such as ground vehicles, ships, helicopters etc.

Propulsion: Several propulsion Tech Mat projects are underway by Pratt & Whitney and General Electric, primarily in the areas of engine diagnostics/prognostics, materials, and LO, however, the details are proprietary.

5.3.2 New Technology Maturation Initiatives

A few new Tech Mat efforts were started in CDP. Some of the most significant are Maintainer in the Loop (MxITL), sponsored jointly by the Requirements and Supportability Directorates, and Prognostics & Health Management (PHM), sponsored by the JAST Directorate. MxITL was described under Requirements in Section 5.2.9. PHM and the complementary Joint Distributed Information System (JDIS) initiative are described below.

Prognostics & Health Management (PHM): Prognostics means detecting conditions that lead to failures before the failures actually occur. During 1997, JSF began an effort to develop an advanced diagnostics and health monitoring system, with the focus of using intelligent mathematical models such as neural networks and fuzzy logic to emulate the healthy and unhealthy operation of the system. This builds upon some of the earlier Tech Mat work, including the Model Based Intelligent Digital Engine Control (MoBIDEC) project conducted by GE, the Advanced Engine Diagnostics & Health Monitoring work by P&W, and the Advanced Strike Integrated Diagnostics project by TRW, conducted under BAA 94-2.

The PHM reasoner-based (or artificial intelligence) approach differs from traditional sensor-based or Built-In-Test diagnostics by transmitting the data from sensors to intelligent reasoners which have been trained to recognize the healthy state and failure modes of the aircraft and its components. Prognostics is the monitoring of data, ideally using sensors already employed in normal flight system-enabling capacities, to recognize trends indicative of known failure modes. Specialized diagnostics sensors will be added only

as necessary to complete the data set. Once an impending failure is recognized, the JSF's PHM system will record the incident and the current environmental conditions into an air vehicle manager, which would take appropriate action. This may include making minor adjustments to the system in question to postpone/isolate the failure, communicating with the autonomic logistics system through JDIS (discussed below) to trigger maintenance events, and/or warning the pilot. Replacing scheduled maintenance and inspection with continuous on-board monitoring is expected to *enable condition-based maintenance*, in which maintenance actions are taken on the basis of the actual condition of a component, rather than on statistical metrics such as time since last inspection. Maintenance man-hours, aircraft downtime, and logistic footprint can all be reduced by the proactive approach of prognostics.

In June 1997, JSF BAA 97-1 was published in the *Commerce Business Daily (CBD)*, requesting proposals that could reliably predict impending failure, and/or rapidly detect malfunctions before proceeding to catastrophic failures. Work was specifically sought in the areas of turbine engine rotor disk crack detection, real-time engine oil analysis, and cable/connector fault detection. Three contracts, totaling approximately $2.8 million, were awarded to small businesses as a result of this solicitation:

- Foster-Miller, Inc., Waltham, MA: On-line, infra-red, oil condition monitoring
- Expertech, Inc., Atlanta, GA: Real time oil debris detection and analysis
- Management Sciences, Inc., Albuquerque, NM: Cable and connector faults and failures

Additionally, Boeing and Lockheed each received an additional $8 million to conduct PHM work in conjunction with their ongoing CDP activities; Pratt & Whitney received $7 million to add PHM tasks to the Tech Mat portion of their CDP propulsion contract; and General Electric received approximately $5 million to develop PHM technologies for the JSF alternative engine. The WSCs, P&W and GE continue to improve and build on their PHM designs. Technical Interchanges Meetings are held on a quarterly basis with the contractors to discuss progress on PHM designs and the maturation of their technologies. In September 1998, P&W completed a major milestone in the refinement of their PHM architecture with completion of the first of two planned seeded fault engine tests: an F100 test engine was instrumented with various advanced sensors, and faults were introduced to determine the ability of these sensors to detect the problems. Expertech excelled with impressive results recorded during the Pratt and Whitney seeded fault and related rig tests. The other two BAA projects, however, were discontinued after initial research did not show sufficient promise of maturing the technology in time for the JSF design.

The programs all proceeded successfully throughout 1999 with all the contractors gaining more maturity on their selected designs. P&W successfully completed a second seeded fault engine test, which is allowing them to selectively chose technologies to be developed on the JSF EMD engines. P&W has also continued work on maturing their area manager for analyzing the data on the engine. Both Boeing and Lockheed have matured their overall system designs. Boeing has successfully completed two demonstrations on their PHM Test Bench. This is a tool that they are using to design the reasoners and analysis tools that will be used on board to analyze data and make decisions on fault detection, isolation and prognostics. Lockheed has also completed numerous demonstrations of PHM technologies and have a design in place that includes PHM on all the subsystems of the aircraft. Both Lockheed Martins and Boeing are in the process of completing Cost Benefit Analyses related to PHM. These PHM studies are predicting huge savings for the life cycle cost for JSF.

Each ASC hosted a PHM TIM, one each in February and March 2000. These TIMs were a forum for the Government team to review the WSC's progress in the PHM area. Also in February 2000, a meeting was held at P&W to discuss their current status and proposed plans for future development of the PHM system for their F119 JSF engine. The analysis of several of the PHM Tech Mat and associated technologies evaluated during P&W seeded fault engine tests continued, conclusions were presented, and decisions were made regarding which sensors to continue to review.

P&W completed a Cost Benefit Analysis (CBA) for the baseline PHM system on the F119 JSF engine in July 2000. Significant savings/cost avoidances were found that further substantiated PHM on the engine. Both WSCs finished PHM CBAs that came to the same conclusion: the potential savings far outweighed the risks involved in developing a comprehensive PHM system for the air vehicle.

The final Boeing PHM TIM and the final LM JDIS/PHM demonstration were conducted in July and August 2000, respectively. Several demonstrations of potential PHM capabilities and PHM/JDIS interfaces were presented. Scenarios of how PHM capabilities would actually be used in operational environments were also provided. Additionally, Boeing performed a demonstration of its reasoner architecture in July. A comprehensive and robust PHM architecture now appears to be well integrated in the aircraft and engine designs, influencing and affecting all aircraft subsystems.

On developing supporting PHM technologies outside of the regime of the WSCs, much was accomplished. Several Phase I Small Business Innovative Research (SBIR) projects that pertain to PHM were awarded funding for 2001, which helps the JSF in its search for increased capabilities. A Phase II SBIR was also awarded funding to develop a system that will perform wiring diagnostics on individual pin and connectors. The Intelligent Component Health Monitor (ICHM) Dual Use Applications Program continued to demonstrate progress toward application to aircraft. A SBIR topic for wireless sensors was proposed and accepted. The GE Intelligent Maintenance Advisor for Turbine Engines (IMATE) program finished on schedule and under budget. An IMATE follow-on study is planned for 2001 to utilize remaining funds, as well as a PHM CBA. A DUST program with GE was initiated for Engine Intelligent PHM. Helicopter HUMS and Navy Integrated Mechanical Diagnostics (IMD) efforts were considered as technology and a lesson learned “feeder” for PHM.

Joint Distributed Information System (JDIS): JDIS is the infrastructure intended to complement PHM. It acts as a conduit for information concerning the health of the JSF aircraft and enables the Autonomic Logistics concept. Once the on-board prognostic/diagnostic system identifies a failure or an impending failure, JDIS must get that information to the right place at the right time, so that the necessary parts, data, and equipment can be provided to the maintenance crew as soon as possible—starting while the aircraft is still in the air. JDIS will include the capability to support a myriad of functions from mission planning to the maintenance supply chain to distributing failure information to the manufacturer for possible reengineering. The combination of the ability of PHM to predict failure and JDIS to provide the information conduit forms the capability for Autonomic Logistics. JDIS is also the repository for JSF-specific software that must be developed, since some functionality required to enable Autonomic Logistics, such as off-board PHM, cannot be achieved by any other DoD or service-specific system.

Both Boeing and Lockheed Martin began extensive programs in 1998 to address JDIS development. Several tests and demonstrations have been conducted and more are planned by each contractor. Two programs evolving in conjunction with JDIS are the Defense Information Systems Agency’s (DISA) Global Combat Support System (GCSS) and the DARPA Advanced Logistics Program (ALP). JSF is hoping to capitalize on the promise that both programs will embody an open architecture and state of the art logistics software. Both contractors are investigating the potential of demonstrating their JDIS program in conjunction with GCSS and ALP. Lockheed and Boeing are working closely with both of these evolving programs and with the existing legacy logistics programs across the services to ensure that JDIS is a marketable commodity and an asset to the JSF.

Both JDIS programs continued successfully throughout 2000. JDIS became an important enabling component in the new Autonomic Logistics support concept for JSF. Both Lockheed Martin and Boeing completed demonstrations of their JDIS systems in 1999. These demonstrations showed an overall implementation of PHM and JDIS into the entire operational and support structure for the JSF.

The final demonstrations in mid-2000 demonstrated an integrated Autonomic Logistics strategy based on the technologies developed in the PHM and JDIS programs. These demonstrations highlighted the WSC

concept to achieve information interoperability and integration with the Services current information systems. It also presented some of the hardware and software the WSCs feel are critical to the development of JDIS and provide the Warfighter the information needed at the appropriate time.

Supplier Utilization Through Responsive Grouped Enterprises (SURGE): The Manufacturing Affordability Development Program (MADP) program identified manufacturing initiatives and approaches currently being used in the aircraft industry which have created significant savings. The outgrowth of MADP is a Defense Logistics Agency (DLA) and JSF-teamed program to improve the efficiency and responsiveness of the supply chain in responding to the highly variable demand for products. By more effectively leveraging industry flexibility, the SURGE program seeks to enable DLA to provide cost effective readiness and surge responsiveness to the warfighter, while demonstrating the life cycle affordability potential for the JSF. SURGE is based on the fact that efficiencies can be gained by arranging the manufacturing of items based on common processes. Lockheed Martin was awarded a contract in late 1998 to demonstrate the "group technology" process for potentially reduced lead-time, greater parts availability, and at a reduced cost. Under Phase I, the development of the grouping process and technology was completed in 1999. The Autonomous Intelligent Agent (AIA), a tool to assist in the grouping of parts based on manufacturing process, was developed and demonstrated.

An additional SURGE contract was awarded by DLA to the Boeing Company in September 1999 to demonstrate the advantages of grouping parts on the F-15, F/A-18 and AV-8B. This will further demonstrate the potential of the SURGE approach. The AIA has been moved to Boeing and is being further refined with the assistance of the original developers. Contractor results have shown a strong indication of their potential to utilize this type of Lean approach in their overall operations.

5.4 Weapon System Concept Demonstration

The two WSC teams, led by Boeing and Lockheed Martin, are rapidly concluding their CDP activities:

- Design, fabricate and flight test two CDAs each, to demonstrate
  - Commonality/modularity among service variants
  - STOVL hover and transition
  - Satisfactory low speed carrier approach flying and handling qualities
- Refinement of their PWSC designs
- Additional concept-unique technology demonstrations

At the beginning of CDP, both WSCs brought on team members who had formerly been on the unsuccessful McDonnell Douglas/Northrop Grumman/British Aerospace JSF team during the previous phase. By the end of 2000, both WSCs had begun flight testing of their Concept Demonstrator Aircraft for CTOL and CV missions, and neared flight testing of their STOVL CDAs. Details of the Weapon System Concept evolution and development is discussed in detail in Chapter 6.

Propulsion-related highlights through 2000 included a successful Preliminary Design Review (PDR) and Critical Design Review (CDR) for the P&W CDA engines and achieving flight clearance for both X-32 and X-35 CTOL/CV designs, as well as substantial testing for the STOVL variants of both designs. In addition, GE had completed core testing of their F120 engine and continued maturation efforts to develop a complete turbofan engine for the winning WSC design. The propulsion system development is discussed below.

5.4.1 Pratt & Whitney JSF F119 Engine Development Program

Pratt & Whitney began CDP with additional funding to complete the preliminary design of the two selected engine designs, SE614 for Boeing and SE611 for Lockheed Martin. The P&W JSF engine design team quickly grew from about 200 to over 800 equivalent full-time staff. The CDP propulsion contract was

awarded in January 1997 for a total value of $805 million. The following month, $30M of additional Tech Mat efforts, as well as the $27 million for work performed between November 1996 and January 1997 while contract negotiations were still underway, were added, bringing the total initial contract value to $861 million. Modifications to the contract through the end of 2000 have raised this amount to $957M. By mid-2000, manpower had dropped below 500 equivalent heads, and dropped another 50% by the end of the year.

P&W began extensive facility modifications (primarily with company funds), building additional test stands for CV/CTOL engines as well as for STOVL tests of the full-up propulsion systems (i.e., with the Roll-Royce and/or Rolls-Royce Allison lift components) at P&W's Government Engines and Space Propulsion (GESP), West Palm Beach, Florida, plant. These facility modifications resulted in a total of four test stands for CV/CTOL tests and one for STOVL operations in the "A-Area" as well as two tests stands (C-12 and C-14) for STOVL operation with multi-component thrust measurement systems in the "C-Area." P&W's capital investment in facility modifications was nearly $13M. Another $5M in facility modifications was also required at the Air Force's altitude test facilities at the Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee, to accommodate the JSF119 engines, since even the CV/CTOL versions are much different than the F-22/F119 engine.

In January 1997, P&W completed the F-22/F119 Initial Flight Release (IFR) configuration Accelerated Mission Test (AMT). This exhaustive 2,000 hr engine evaluation showed the durability of the F119, including the common JSF119 parts, and cleared the engine for flight testing on the EMD F-22 aircraft. The JSF Lockheed Martin and Boeing engine configurations both share a common core (i.e., compressor, combustor and high pressure turbine) with the F-22/F119 engine and benefit from more than 7,000 hours of development and flight tests of the F-22/F119 engine core. The fans, low pressure turbines, and nozzles are tailored for each WSC's concept with additional components added for the STOVL variants.

A combined P&W PDR for both the SE611 and the SE614 was held on 10-14 March 1997. The engine PDR was held over 5 days, with 5 sessions run concurrently, encompassing over 130 hours of presentations. Col Nyalko, the JSF Systems Engineering Director, who was the PDR chairman, stated, "The maturity of the Joint Strike Fighter propulsion system design is well beyond what we expected to see at PDR." This was indeed a necessity, due to the extremely challenging pace of the engine development program: component CDRs would begin only five months later.[111]

During mid-1997, key F119 engine components, including those used on the JSF versions of the F119, underwent a series of structural tests simulating conditions that will be encountered in operational service. The test series of the Component And Engine Structural Assessment Research (CAESAR) engine core took place in P&W's Wilgoos test facility in East Hartford, Connecticut. CAESAR is a joint IHPTET/P&W program to assess promising propulsion technologies in a structurally demanding environment. Turbine temperatures up to the maximum required for the CDP engines were attained. The tests confirmed the capability of the standard F119 turbine blades and vanes to be used in the CDP engines, while also quantifying the improvement provided by advanced cooling schemes (i.e., Superblade and Supervane) to be used for the production JSF engine.

Following core engine disassembly and detailed inspection, these components were installed in the full-up CAESAR engine for cyclic endurance exposure to complete the assessment, with tests beginning in December 1997.[112] Testing continued through 1998, with 1505 AMT TACs (335 hours) accumulated. These tests demonstrated the cyclic endurance capability of the high pressure turbine Superblade and Supervane designs. The results are being used in the development of the JSF design. The tests also demonstrated the capability of gamma-Titanium Aluminum high pressure compressor blades from GE, Allison, Rolls-Royce, and P&W.

The P&W CDRs started at the beginning of August 1997 and during the ensuing three months, 34 individual technical reviews and a five-day executive summary (held 20-24 October 97) were successfully

completed. The CDR was conducted in a rolling review process, which allows the individual component designs to be reviewed sequentially and in great depth. CDR demonstrated that the technical performance was on track and that P&W was aggressively working to meet the extremely challenging First Engine To Test (FETT) schedule goals. The P&W CDR Executive Summary/PMR was held for General Kenne on 6-7 November 1997.

Engine fabrication began in March 1997 with the machining of the titanium billet that would become the first stage fan integrally bladed rotor (IBR). In June 1997, Pratt & Whitney selected Thiokol affiliate Howmet to supply 20 sets of turbine blades for the JSF CDA engines, ten sets each for Boeing and Lockheed. Engine assembly began when the first JSF compressor section was completed on 19 September 1997. The first JSF core was completed on 28 January 1998 at P&W's manufacturing plant in Middletown, Connecticut. The core is common with the F119 and was built on the same assembly line as the F-22's F119 engine. The core was then shipped to P&W GESP to be assembled with the remaining JSF unique parts.[113]

Figure 50: JSF Engine First Chips

The engine test program is designed to clear the engines for flight in the shortest amount of time as affordably possible. Both Boeing and Lockheed Martin have similar engine test programs, each using a total of six engines for well over 1000 hours of ground test time. By the end of 1999, both WSCs had over 700 hours of engine test time each; the current status of the six engines for each WSC is summarized in Table 22 and Table 23. The AMT, the final flight clearance test consisting of twice the expected engine usage in the flight test program as well as testing for high cycle fatigue (HCF), has been initiated for each design. Flight clearance has to be completed before the first flight of the JSF CDAs in 2000. Pratt expects to achieve flight clearance for the CTOL powerplants by early 2000, and STOVL flight clearance by mid-2000.[114]

Table 22: Boeing JSF Engine Testing Through December 1999

Engine	WSC	Configuration	Purpose	Status	Test Facility
FX651	Boeing	JSF119-614C	CTOL development	Planned testing complete; undergoing additional testing	P&W/AEDC
FX652	Boeing	JSF119-614S	STOVL development	Testing underway	P&W
FX653/ YF006	Boeing	JSF119-614C	CTOL altitude testing/ flight spare	Undergoing vehicle integration tests	P&W/AEDC
FX654	Boeing	JSF119-614S	STOVL altitude testing/ AMT (flight clearance)	Testing initiated	P&W/AEDC

YF004	Boeing	JSF119-614C	CTOL flight engine	Testing initiated	P&W
YF005	Boeing	JSF119-614S	STOVL flight engine	Awaiting assembly	P&W

Table 23: Lockheed Martin JSF Engine Testing Through December 1999

Engine	WSC	Configuration	Purpose	Status	Test Facility
FX661	Lockheed	JSF119-611C	CTOL development	Testing complete	P&W/AEDC
FX662	Lockheed	JSF119-611S	STOVL development	Testing underway	P&W
FX663/ YF003	Lockheed	JSF119-611C	CTOL altitude testing/ flight spare	Altitude testing underway	P&W/AEDC
FX664	Lockheed	JSF119-611S	STOVL altitude testing/ AMT (flight clearance)	AMT testing initiated	P&W/AEDC
YF001	Lockheed	JSF119-611C	CTOL flight engine	Assembly complete	P&W
YF002	Lockheed	JSF119-611S	STOVL flight engine	Assembly underway	P&W

Engine testing began on 11 June 1998 with the commencement of testing on the Lockheed Martin SE611 configuration; this was followed 10 days later with the Boeing SE614.[115,116] Although two months behind the extremely aggressive 15 April 1998 contract goal date, the two engines designs were brought to test within 18 months of contract award through close coordination between P&W, the WSCs, and the JSFPO.[117]

Figure 51: Lockheed Martin SE611 First Engine to Test

These initial tests were conducted at P&W's GESP West Palm Beach facility and included component performance evaluations, compression system stability demonstrations, vibration surveys, operating system functional verification, and control software verification. The JSF119-611 engine was then instrumented for simulated altitude testing at AEDC. The Boeing JSF119-614 was kept at P&W GESP for further testing before it was shipped to AEDC in early 1999. In over 120 hours of combined testing, the Boeing JSF119-614 and Lockheed Martin JSF119-611 engines demonstrated component efficiencies higher than

anticipated, turbine temperatures lower than predicted, and very low vibration levels. In addition, compression system stability margins and control software were verified.[118]

The STOVL engines began testing in mid-November 1998 on P&W's unique test stands that have been designed to measure forces in all directions to properly characterize STOVL engine operation and its relationship with the aircraft vehicle management system. Through the end of 1998, P&W had four JSF119 engines under test, having accumulated a total of approximately 200 hours.[119]

By the end of 1998, the Lockheed Martin SE611 STOVL engine, designated FX662, operated with the Rolls-Royce Allison Lift Fan both engaged and disengaged, and actuated the three bearing swivel nozzle from 0-90° at full STOVL power; the Lift Fan was also run at full power to obtain critical stress and performance data. Figure 52 shows the FX662 on the STOVL test stand: the Lift Fan nozzle can be seen between the two metal intake ducts at the bottom left of the photograph; to the left of center is the left roll duct and nozzle.

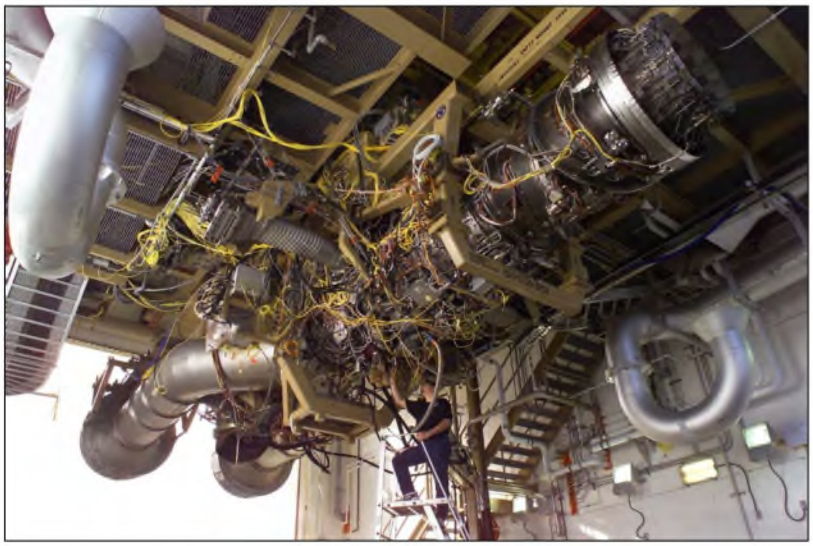

Figure 52: Lockheed Martin FX662 STOVL Engine on the A-9 Test Stand

The nozzle is shown in the 0° position in the upper right of Figure 52, and a collage of the nozzle rotating is shown in Figure 53. Lift Fan testing progressed relatively slowly through the end of 1998; excessive vibration levels in the shaft and clutch required Rolls-Royce Allison to rebalance the components before testing could resume. Despite this, the Lift Fan was run to full flow and full speed. Lift Fan testing produced no major surprises.

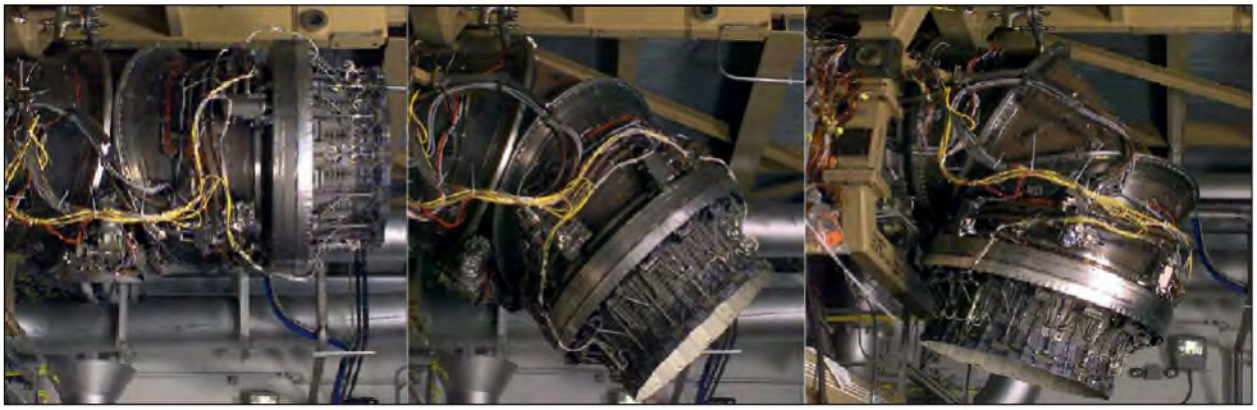

Figure 53: Three Bearing Swivel Nozzle at 0°, 40° and 105° of Rotation

On 1 February 1999, FX662 accomplished two successful STOVL conversions, simulating operation of the propulsion system during the X-35's transition from STOVL flight to conventional wing-borne operation and back. In this demonstration, FX662 was initially started in the powered lift mode with the lift fan engaged. After achieving steady-state power conditions, a Lift Fan disengagement was commanded. The disengagement went smoothly with all propulsion system effectors operating as desired. A clutch engagement was then commanded and the clutch successfully engaged the Lift Fan and quickly brought it to speed. Again all propulsion system effectors operated as desired and the engine maintained steady power operation. The entire process was then repeated for another conversion cycle.[120]

Lockheed Martin STOVL propulsion system testing continued through 1999, demonstrating Lift Fan engagements at varying speeds from idle to 75%, typical of a short takeoff or vertical takeoff sequence. A high-power clutch engagement of the Lift Fan was conducted on 28 August 1999. The Lift Fan was engaged by the clutch and locked to the driveshaft while FX662 was operating above the typical in-flight conversion power setting. The system was then converted from conventional flight mode to STOVL mode and back to the conventional configuration automatically, under computer control, without any engine or Lift Fan anomalies. The test verified the Lift Fan's capability of engaging and disengaging at any engine speed, under a variety of conditions.[121]

The Lockheed and Boeing STOVL propulsion systems development was repeatedly hampered by oil leaks, thermal stresses, vibrations and missteps, resulting in much fewer test hours (and test points) than planned. This has caused delays in developing STOVL control logic and could delay STOVL flight clearance from the planned dates.

From March to mid-July 1999, the CTOL FX661 test engine underwent conventional engine developmental testing in the C-2 and J-2 test cells at AEDC. The simulated altitude testing evaluated all design aspects of a conventional fighter engine, including structural and component assessment, and performance, operability, stability, controls, augmentor, and nozzle development. In all cases, engine performance met or exceeded predictions. FX661 completed more than 330 hours of altitude testing in the two cells. The tests validated the complete X-35 demonstrator flight envelope, with excellent operability demonstrated throughout. The engine control logic for up-and-away flight for all three JSF aircraft variants was also developed and successfully tested. Successful augmentor operation was verified for both the CTOL and STOVL (three bearing-swivel) augmentor ducts. These tests also confirmed an acceptable airstart envelope for the demonstrator aircraft.[122]

The Boeing engines have similarly been tested in both CTOL and STOVL modes, with the first Boeing STOVL engine starting tests on 22 November 1998. As of the end of 1998, both Boeing engines (FX651 CTOL and FX652 STOVL) had been tested at sea level conditions at P&W; FX652 can be seen in Figure 54 being tested on the six-axis C-14 STOVL test stand. This stand was previously used to test the large

PW4000 commercial engine. The elevated mounting height allows testing of the JSF engines in STOVL mode without negative effects from exhaust gas re-ingestion. Although the engine included the lift module and spool duct, the two-dimensional cruise nozzle and the jet screen had not yet been installed. A removable plate (right extreme of Figure 54) was inserted into the slave nozzle to simulate nozzle closure during STOVL operations. FX651 was shipped to AEDC for simulated altitude testing in January 1999.

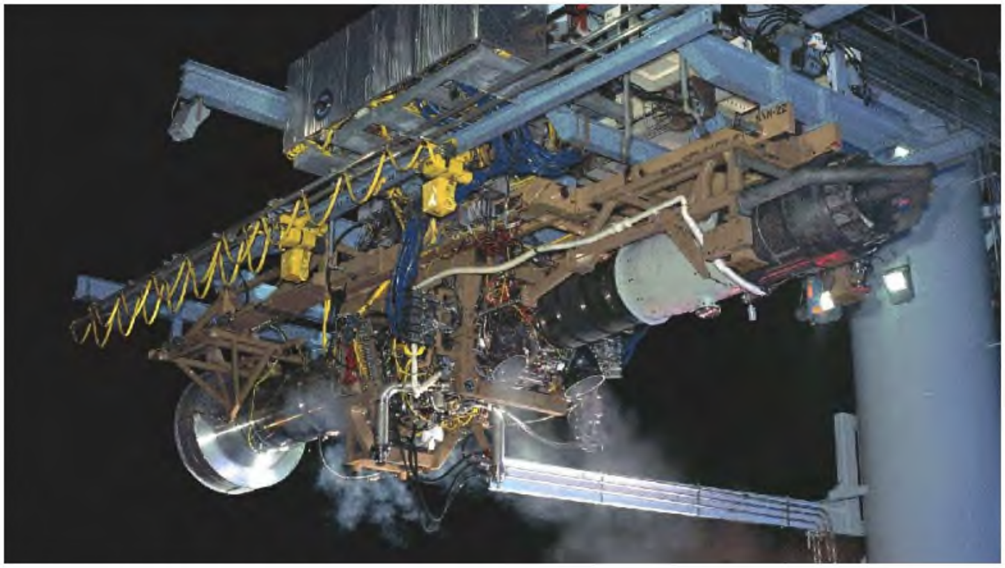

Figure 54: Boeing STOVL Engine FX652 on the C-14 Test Stand (late 1998)

By the end of 1998, testing of both STOVL designs had been conducted in STOVL mode at maximum power, maximum flow and maximum rotor inlet temperature conditions. The STOVL flow deflectors (butterfly and diverter valves and the three bearing swivel nozzle) were each fully deflected during the tests. The tests also demonstrated that the low pressure turbines will be able to withstand the transition from CTOL to STOVL mode (i.e., during nozzle deflections, valve openings, etc.). Teardown inspections were also encouraging.[123] By mid-1999, the first Boeing two-dimensional cruise nozzle had begun tests (Figure 55).

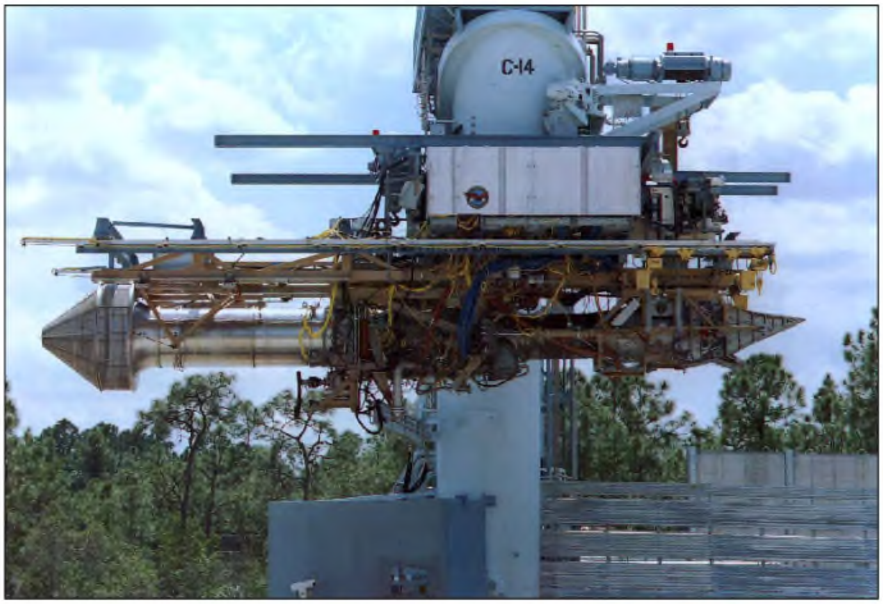

Figure 55: Boeing STOVL Engine with 2D Nozzle (Mid-1999)

On 4 November 1999, the first flight test engine completed assembly (Figure 56). The engine then began its acceptance test, but excessive engine vibrations required that the engine be disassembled. The investigation into the cause and solution continued through the end of 1999.[124]

Figure 56: Boeing First Flight Test Engine YF004 (November 1999)

In conjunction with the WSC EMD planning, the JSF Propulsion Management Team developed a baseline (common to both WSCs) EMD plan. This plan included the number of engine test assets, test hours and the test schedule. The propulsion system acquisition strategy was also developed: the "IPT-Managed" propulsion system philosophy that was pioneered in the CDP phase (see Chapter 8 Acquisition Reform and Streamlining), will be continued (with some improvements) in EMD. The WSC will still be responsible for the Total System Performance (TSPR), and the propulsion contractor responsible for integrated propulsion system performance. To better facilitate this in EMD, the lift systems will be subcontracted through P&W.

In a 12 August 1999 statement, P&W President Louis R. Chênevert announced that P&W would move its Large Military Engine business from West Palm Beach, Florida to Connecticut in order to reduce the costs of engine design, development and production, and provide more comprehensive support for all P&W engines in the field. This was a reaction to a continuing decline in both commercial and military production volume. Military program offices (including those working on JSF), systems engineering groups, customer service and other administrative functions began moving early in the second quarter of 2000 and the rest by the end of 2000. Test operations remained in Florida. More than 1,000 employees remained in West Palm Beach to operate engine test facilities and the Space Propulsion business based there. The net reduction was about 1,500 positions across Pratt & Whitney.[125]

During 2000, altitude testing and the AMTs for both WSC's CTOL configurations were complete. The Lockheed engine, for instance, completed 125 hours of altitude testing in February 2000 at AEDC (this was in addition to over 330 hours of altitude testing in 1999). Test objectives included verification of performance, fan and compressor stability, engine transient operability, stall recoverability, air start envelope, control system operation, and augmentor performance and stability. [126] P&W completed the final segment of CTOL testing – the high-cycle fatigue and accelerated mission testing – at sea-level conditions in April 2000. The AMT engines were subjected to more than double the operating time/events expected during the flight demonstration program in terms of total engine operating time, total hot section time, total augmentor (afterburner) time and number of augmentor lights. Again, for example, the Lockheed engine demonstrated: 193 hours of operating time, 460 total accumulated cycles, 17 hours of augmentor time and 680 augmentor lights from various power settings. During the AMT, engine operation expected during subsonic and supersonic flight testing, ground testing, and field carrier landing practice was continually cycled, representing more than 177 missions. [127]

Both CTOL flight test engines were delivered to the WSCs by March 2000 and flight clearance for both designs was granted by late May 2000. By the end of the year, Pratt & Whitney had tested the Boeing and Lockheed Martin engine designs for a total of about 3,000 hours, approximately equally split between the two WSCs. About 20% of this time was testing in STOVL modes. STOVL AMT testing was well underway by the end of 2000.

During 1999, the JSF PO began developing the RFP for the EMD propulsion contract. In October 1999, Pratt & Whitney signed MOAs with Rolls-Royce to begin to negotiate a contract for RR to supply the STOVL lift system for the JSF119 EMD propulsion system for JSF.[128] Early drafts of parts of the RFP were released in February and October 1999, with the entire final draft RFP released on 10 December 1999.[129] The final RFP was released on 19 July 2000, with an update in early 2001.

P&W submitted their EMD proposals in support of Lockheed Martin and Boeing EMD programs on 19 September 2000. The entire propulsion system will be funded directly by the government to P&W (i.e. GFE). The proposal values are over $3B (in TY$), including the STOVL lift system development costs, which will be subcontracted to P&W. This makes the JSF propulsion system development the most expensive in DoD history.

5.4.2 General Electric JSF F120 Engine Development Program

Phase II of the Alternate Engine Program (AEP) was kicked off on 7 November 1996. Work was accomplished under an extension to the Phase I contract until the $96M Phase II contract was officially signed on 13 February 1997. Also in February, Mearl Eismeier was assigned as the full-time AEP Project Manager. The Initial Design Review (IDR) was held on 28 May 1997. Phase II consists of the development and testing (in mid-2000) of a common F120 core that is suitable for both WSCs participating in the current phase, as well as Tech Mat tasks and Risk Reduction for the WSC alternate engine designs. Starting in 2001, after the final downselect for EMD, Phase III of the Alternate Engine Program will develop the appropriate concept-unique low pressure components. EMD of the JSF F120 is currently planned to continue until competition occurs for Lot 6 in 2011.

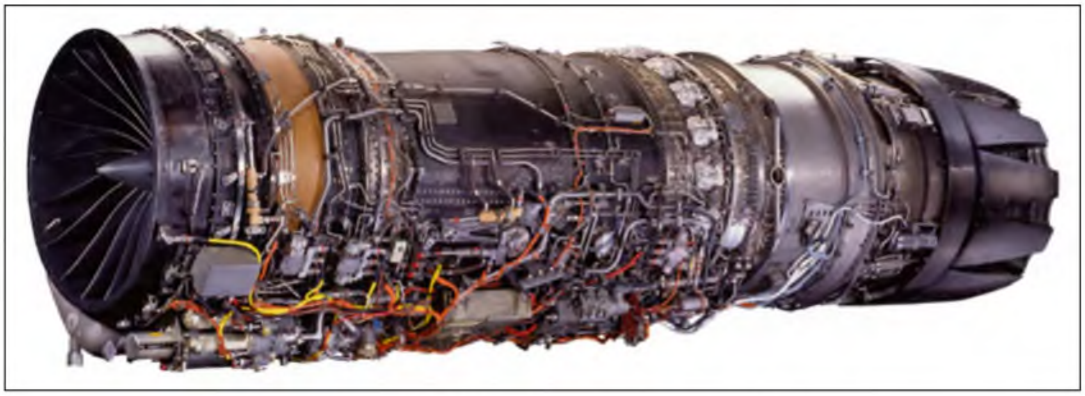

Figure 57: GE YF120 With an Axisymmetric Nozzle

GE has developed a partnership with Allison Advanced Development Company (AADC) and Rolls-Royce, Plc. to develop the Alternate Engine. For the JSF-F120, GE is developing a multistage blisk compressor, radial augmentor and dual control system, and advanced exhaust system components. AADC and GE are jointly developing a coupled turbine system (an integrated high-pressure/low-pressure counter-rotating design), while AADC is responsible for the combustor/diffuser system and the gearbox. Rolls-Royce is developing an increased-flow, three-stage, long-chord hollow titanium blisk fan, applying their significant hollow fan blade experience. [130]

On 1 December 1997, the JSF Program Management Advisory Group (PMAG) was chartered by ASN(RD&A), Mr. John Douglass, in response to the 1998 Defense Authorization Act concerning the JSF AEP; Congress required DoD to certify that the AEP was fully funded and withheld 10% of the FY98 funding for JSF until that requirement was met. The senior-level PMAG was tasked to review the technical and programmatic issues of the AEP, determine its costs and benefits and report its findings. Co-chaired by RADM Joe Dyer, then-NAVAIR Assistant Commander for Research and Engineering, and (b)(6) [redacted] Air Force Propulsion Product Group Manager, the PMAG met 15-19 December 1997 and 5-9 January 1998, and briefed Mr. Douglass and Mr. Money (SAF/AQ) on 12 January 1998.

The PMAG determined that developing an alternate JSF engine had significant benefits in the areas of contractor responsiveness, industrial base, readiness and international benefits. Finding marginal, but not *significant*, benefits in the areas of cost savings and additional growth capabilities for the JSF production phase, the PMAG found that the AEP did not provide a benefit to EMD risk reduction without restructuring the program to conduct development concurrent with the P&W primary engine. The PMAG recommended that JSF proceed with the AEP as was currently planned. The PMAG did not address, however, whether the services could afford the development of the alternate engine.[131] USD(A&T), Mr. Jacques Gansler, reported to Congress on 13 February that:

> …the JSF program contains sufficient funding to carry out an alternate engine development program that includes flight qualification of an alternate engine in a Joint Strike Fighter airframe….It is estimated that over $1 billion would be necessary for its Engineering and Manufacturing (EMD) phase….[which] would begin no sooner than FY04. The alternate engine program, schedule, and budget for FY04 and beyond are outside the scope of the Department's current FYDP. However, the Department recognizes the benefits of the alternate engine program and is structuring its option for implementing a competitive program beyond FY03. The Department will fully fund the selected option in its outyear program.[132]

This funding option resulted in the first competition between the P&W F119-derivative engine and the GE YF120-derivative scheduled for Lot 7, as discussed in section 4.3.3.

The focus of the GE Phase II Core PDR on 14-16 January 1998, was on the preliminary design of the product core, defining the product core configuration, and identifying the test article configuration. The Government/WSC team reviewed the design status of each GE, Rolls-Royce Allison and Rolls-Royce core

engine component to evaluate the progress, technical adequacy and risk mitigation, and to ensure the design met both Boeing and Lockheed Martin PWSC requirements.

For the CDR, GE conducted “rolling CDRs” as P&W had previously. The CDR kick-off meeting was held in June 1998, and the final component CDR took place in December 1998. The CDR focus was on the detailed design of test article core and test article hardware, including instrumentation/test provisions as well as cost, schedule, and risk issues.

A number of component tests were conducted in support of the alternate engine core development during CDP, including diffuser rig, combustor single cup and 90º sector rig tests and others. Through the end of 1998, manufacturing of core components was well along and most major forgings and castings were available.

The Phase II Core CDR Outbrief was held on 15 January 1999. The successful completion of CDR allowed the team to release hardware for component testing, leading to the full core engine test in mid-2000. Key component-rig tests during 1999 included: the turbine at GE, the fan at Rolls-Royce, and the combustor at AADC.[133]

In June 1999, GE announced that the Alternate Engine team had reached agreements with [redacted] of The Netherlands; [redacted] will form and lead a consortium of Dutch, Norwegian, and Danish companies to join in the design, development, and manufacture of the JSF-F120 propulsion system. [redacted] a division of [redacted] specializes in a wide range of production machines and systems, and in the manufacture of aviation components. [redacted] is the sole supplier of exhaust nozzle flaps and seals for GE F110 fighter engines and is expanding its relationship into other GE product lines. [redacted] also supplies the inlet scrolls for the Rolls-Royce Model 250 engine. The consortium members will have the opportunity to participate in other GE, RR, and Allison programs.[134]

On 25 June 1999, the JSF PO signed a contract for Phase III of the JSF F120. The Phase III effort consists of a firm requirement for $115 million and an option for $325 million, covering engine development activities for the period of October 2000 to September 2004. The Phase III contract, which also includes component and subsystem testing, will lead to full JSF F120 engine testing for the winning WSC design in the first half of 2003.[135] The first part, Phase IIIa (Pre-EMD) – risk reduction and rig testing of non-WSC specific components – began after the conclusion of the core tests, on 16 October. Phase IIIb (EMD) – designing, building and ground testing an engine configured for the winning WSC – will begin once the JSF program enters EMD.

By the end of 1999, most of the components for the JSF-F120 core had been fabricated and were undergoing assembly for the core test. The assembled core was delivered to the Rolls Royce Indianapolis test facility in late July 2000. Testing continued until 1 October 2000. Core test consisted of 78 hours of simulated engine testing to determine performance and operability characteristics of the core. GE and RR collected sufficient data to understand the operating conditions, identify potential problem areas, and support the Phase III design effort.

The concept of Engine Interchangeability (initially called “Plug and Play”) is critical to the development of the Alternate Engine. Engine Interchangeability envisions that the turbomachinery of both contractors (P&W and GE) could be interchanged with a no modifications in the aircraft. The lift system, inlet system and exhaust system, therefore, would be common for both engines, with a minimum (if any) changes necessary to work with either engine.

The objective of the Engine Interchangeability effort is to minimize development and support costs while maximizing production and operational benefits, by developing two competing engines that are physically and functionally interchangeable with: all three aircraft variants (CTOL, CV, and STOVL); the air vehicles’ subsystems (environmental, thermal management, fuel); the common propulsion system hardware; and the JSF Autonomic Logistics System.

The JSF PO, in concert with P&W, GE, Boeing and Lockheed Martin, developed a contractual approach to implement this strategy which ensures equity will be maintained in competition. The WSCs will develop and implement an EMD propulsion management structure with equal representation from P&W and GE. Both companies will be involved together in the design, development and qualification of the common (non-competitive) propulsion system hardware. The same propulsion system-level requirements (thrust, weight, reliability, etc) apply to both the JSF119 and JSF F120 engines, and P&W and GE will work with the WSCs to develop a JSF propulsion autonomic logistics system that will support both engines with minimal modifications. P&W and GE are currently working technical trade studies with Boeing and Lockheed Martin to determine the changes necessary to the JSF119 engine, JSF F120 engine, and the common propulsion system hardware to make both engines physically and functionally interchangeable, while meeting the WSC's propulsion system requirements. P&W and GE have been exchanging mechanical design and performance data in support of these trade studies. More detailed studies will begin after EMD start to determine the final JSF119, JSF F120 and common hardware designs.

It should be noted that Congressional support for the Alternate Engine Program has continued to be consistently strong since its initiation in FY96 (see 4.4.4). In nearly each year of CDP, Congress has added funds to JSF over and above the amount requested in the President's Budget; although there was no additional funding for the F120 program (perhaps due to the overall Congressional program slip), Congress restated its support of the engine competition. The final DoD appropriation increases are as shown in Table 24.

Table 24: Congressional Plus-Ups for Alternate Engine Program

FY97	FY98	FY99	FY00	FY01
+$10 M	+$15 M	+$7.5 M	+$15 M	0

These funds are generally stated to be to accelerate the program as well as for additional risk reduction. For example, the draft version by the House of Representatives (which proposed an additional $30 M) of the FY00 Defense Authorization bill notes:

> The committee continues its strong support for the development of an alternate engine to ensure sustainment of critical industrial base capabilities, control of engine cost growth, and reduction of risk to the reliability and maintainability of the planned fleet of 3,000 JSF aircraft. The committee is concerned that while the Department now states a commitment to development of an alternative engine for JSF, the planned funding levels outlined to support that commitment do not enable cost-efficient and timely completion of the effort.[136]

While the draft version of the FY00 Defense Authorization by the Senate (which proposed an additional $15 M) states:

> The committee remains concerned that development of an alternate engine for the JSF will not proceed to a point where it represents a viable alternative and reduces risk for the vertical and short take off and landing (V/STOL) JSF variant.[137]

The defense committees have generally expressed concern that a delayed introduction of the alternate engine will reduce the viability of the competition. This is because many Allies may tend to buy the same configuration as the initial US purchases, rather that select an engine that has less (or no) operational experience at the time of their decision, effectively locking GE out of the competition for foreign military sales. The amount of additional funds, however, do not contribute sufficiently to accelerating the program, since only limited work can be done in maturing the low pressure system prior to the JSF Milestone II downselect for EMD in 2001.

5.5 Planning for EMD and Beyond

5.5.1 Source Selection Planning

Although some top-level planning guidance for the EMD Phase of JSF was given to the contractors as part of the CDP solicitation, planning began in earnest in late 1997. The overall approach was developed during 1998 and then briefed to the Acquisition Strategy Advisory Group (ASAG) in October 1998. The ASAG was a top-level decision/advisory group chartered to give guidance on EMD acquisition planning issues. The ASAG direction was then followed by working level efforts to develop the next step of planning. The "final products" of these government/WSC IPT working groups were presented to the contractors in EMD Planning Team meetings. The contractors then provided feedback and the iteration continued.

As discussed in Section 4.2.6, the continuous cost/performance trades, which appear in each of the COPT reports, were coordinated with the JIRD/JORD development. This link promoted iterative and interactive requirements and cost target development, culminating in an Analysis of Alternatives (AOA) and a JSF performance-based specification (the JMS). The AOA is being conducted by the Institute for Defense Analyses (IDA). It will be through these cost/performance trades that affordable JSF requirements are to be established and the PWSCs evolved.

The COPT updates fed into the JIRD/JORD releases that in turn facilitated development of interim specifications. This culminated in a single contractual Joint Model Specification for the JSF weapon system, based on the final JORD. This effort was led by SE and supported by the other Directorates, with both WSCs actively participating. As discussed in Section 5.2.9, this single specification embodied only the minimum requirements necessary to effectively manage the program. It also provided the WSCs with the maximum trade space possible to satisfy those essential performance requirements within the cost constraints of the program (in keeping with CAIV). Contracting for aggregated performance requirements maximizes the WSC's freedom in the requirements allocation (flowdown) process, as well as in hardware and software design efforts. This approach also captures all of the essential performance requirements in a single specification, rather than having several documents, each with increasing levels of specification detail. The single specification includes requirements normally presented much lower in a traditional specification tree, while avoiding unnecessary contractual documents; this provides streamlined program documentation.

To solicit proposals for EMD, JSF issued a Call For Improvements (CFI) instead of a traditional Request For Proposal. This is an acquisition-streamlining concept developed by SAF/AQ that allows a tailored RFP to be submitted to the contractors currently competing on the program. As the CFI becomes more finalized after each step, the additional course is again presented to the ASAG. The initial release of material for the CFI to the contractors took place in January 1999. The EMD source selection evaluation approach was developed during 1999, approved by the ASAG that August and then provided to the WSCs. This information forms one of the key incremental releases of CFI material to the WSCs that took place in 1999.

The first draft CFI was released on 29 June 2000. A Pre-Solicitation Conference For Draft Call for Improvement was held at the JSF PO on 12-14 July. The first draft was followed by updates on 24 August, 21 September and 13 October. This culminated with the final CFI on 13 November. This final release was timed to avoid any possible influence on the 2000 presidential election. The sixth floor of the JSF PO offices in Crystal Gateway 4 was converted into the source selection facility. Additional spaces on the tenth floor of CG-4 were leased to house the SE, X-32, X-35 and Propulsion Directorates.

5.5.2 EMD and Production Plans

Notional EMD plans were originally developed in 1996 as part of the RFP development for CDP (see Figure 58). A series of major events in the subsequent years, however, led to significant changes. The initial notional EMD plans and schedules were based on contractor inputs, based on JIRD I, which included only the major aircraft design drivers, broad avionics and support concepts, and only two air-to-ground and one air-to-air weapons to be qualified for internal carriage. Under these constraints, concurrent operational testing and Milestone III decisions for the three service variants were seen as possible.[138]

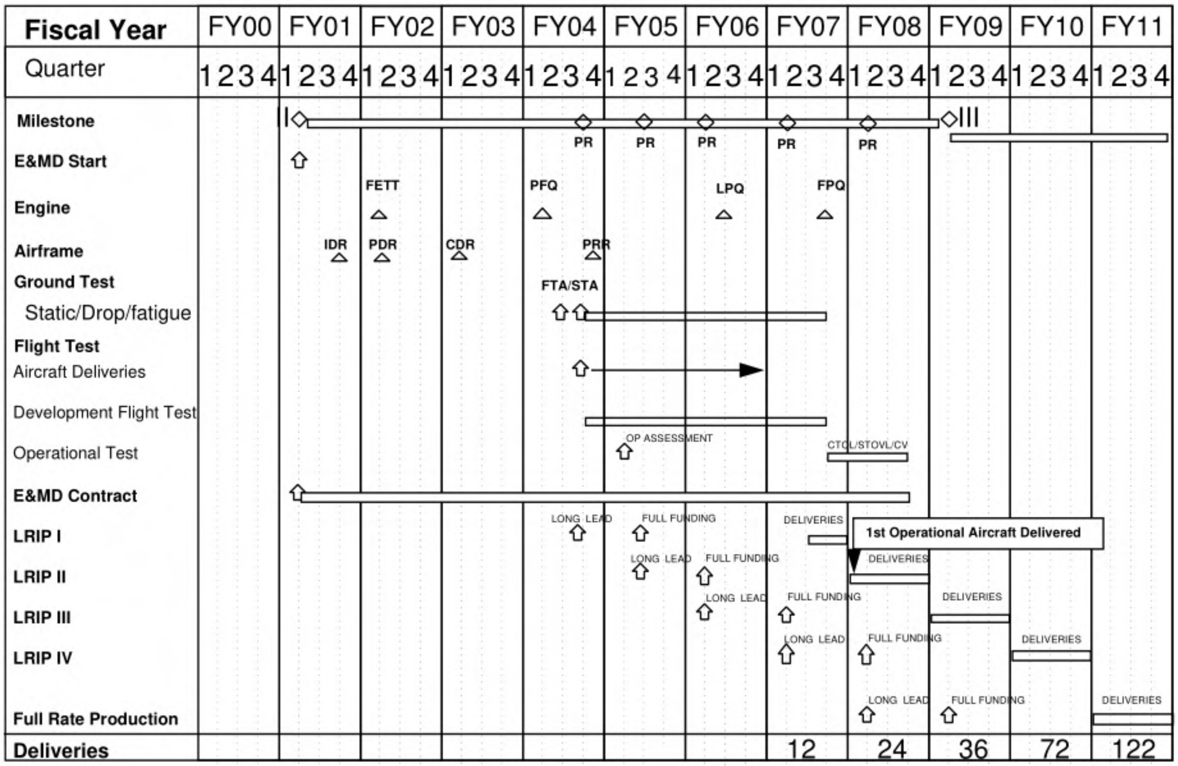

Figure 58: Notional EMD Schedule (1995)[139]

By 1999, however, after several additional iterations of the requirements, culminating in the Draft JORD, extensive refinement had been conducted resulting in detailed service mission, support infrastructure, and C4ISR requirements. Furthermore, more extensive multi-service internal and external weapons sets were also defined in the JORD. Combined with the change in production profile in May 1997 as a result of the QDR, a block approach with staggered operational was developed.[140]

This incremental block approach to combat capability for the early low-rate initial production (LRIP) lots of aircraft (see Figure 59) accommodates mission systems hardware and software development and stores qualification testing, and provides a moderate risk EMD program with shorter cycle time for delivery of an initial combat capability to the warfighter. The JSF evolutionary acquisition strategy provides the Block 1 initial combat capability (AMRAAM and JDAM) delivery at 90 months after EMD start. Blocks 2 and 3 build upon this initial combat capability to deliver the remaining threshold functionality stated in the JORD.[141]

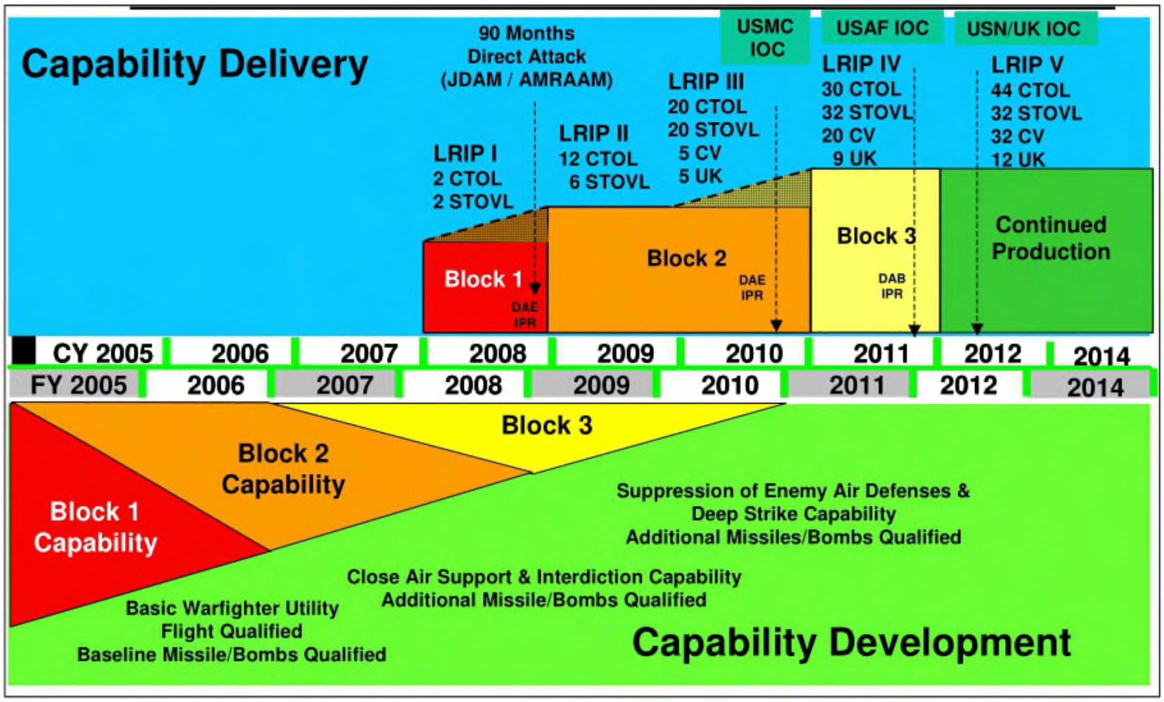

Figure 59: Block Approach for an Evolutionary Combat Capability (2000) [142]

The early blocks emphasize establishing the hardware architecture, while building up to full software and integrated capability over time. Any hardware that is planned for later blocks will be "designed-to" in the first block, to ensure aircraft space, power, and cooling is available. The block approach emphasizes ease of retrofit for future development blocks, addressing the need to maintain weapon systems development and integration capabilities throughout the life-cycle.[143]

In order to stay as close as possible to the planned topline funding profile, the procurement profile laid out in the QDR report had to be slightly modified. The CTOL first flight requirement date was maintained at 42 to 48 months after contract start. The EMD program is planned to begin in Fall 2001, and the JSFPO is using bridge contracts to the winning WSC and P&W to preserve critical manpower resources for an efficient ramp-up at the start of EMD.[144]

The development of the three blocks will reduce risk to an acceptable level, allow IOCs for the services that meet their modernization plans (2010 for the USMC, 2011 for the USAF, and 2012 for USN and UK), and keep costs within manageable limits. Block 1 develops an aircraft that meets basic warfighter needs – a flight-qualified airframe with avionics open architecture, basic functionality, and baseline missiles and bombs (AMRAAM and 1000 lb or 2000 lb JDAMs). Block 2 continues avionics development providing additional functionality for close air support and interdiction capabilities and qualifies additional missiles and bombs. Block 3 concludes avionics development providing suppression of enemy air defenses, deep strike capabilities as well as qualification of additional missiles and bombs. The block development approach balances risk to provide operational capability increments starting with the strong foundation established in Block 1 to the full JSF air system threshold capability with key weapons at the conclusion of Block 3, as discussed in Section 5.2.8. Support and training will be included as a major component of the block development process to ensure the needed training and support capabilities will be developed and verified concurrently with the air system. The block approach concept was approved by the SAE in late 1999. The final ASAG was held in September 2000.[145]

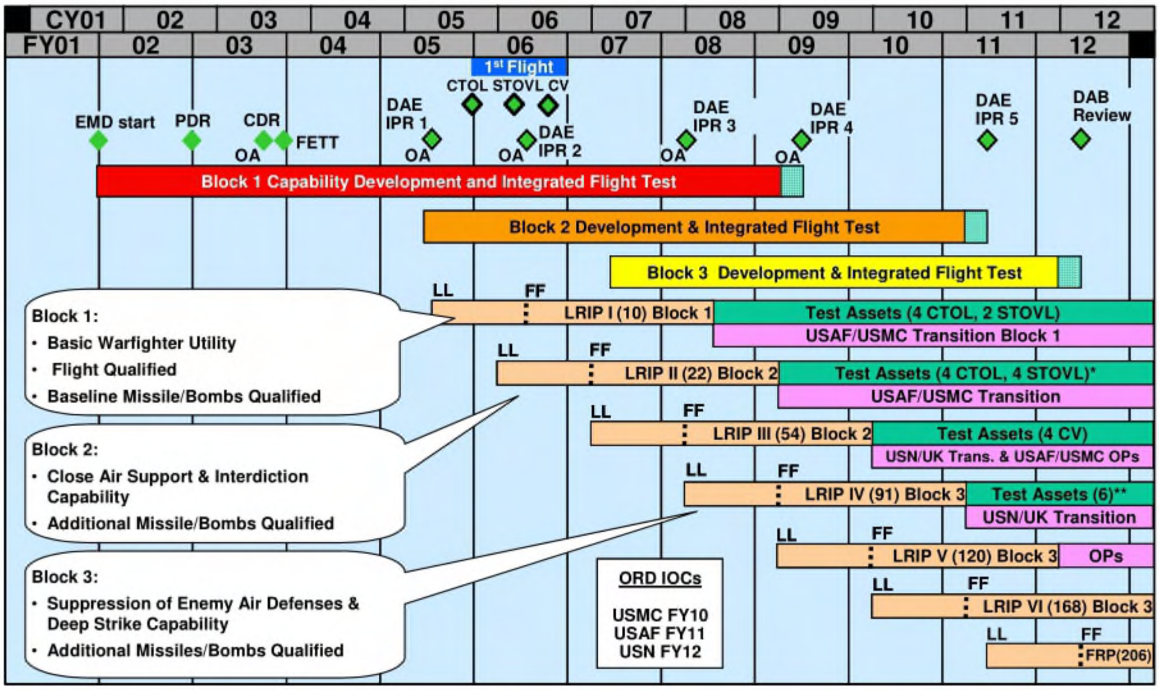

Figure 60: Evolutionary Combat Capability EMD Program (2000) [146]

The JSF EMD Program will involve the Defense Acquisition Executive (DAE), i.e. the Undersecretary of Defense for Acquisition, Technology and Logistics, USD(AT&L)*, oversight in the JSF program will differ from a traditional MS III-driven process. The DAE reviews will consider cost and schedule performance, operational effectiveness and suitability, technical maturity, test accomplishments, and progress towards the EMD exit criteria. DAE reviews will occur at key points in the program including LRIP long lead and full funding approval points and will provide the basis for approving obligation of procurement funds for LRIP, full-production, and multi-year contracts. The final review will include the entire Defense Acquisition Board (DAB) prior to the formal conclusion of EMD and authorization for full rate production.[147]

In July 2000, the complete propulsion system was also approved to be developed as government funded development (i.e. GFE), with the exhaust and lift system components being subcontracted by Pratt & Whitney. GE will receive a GFE contract to develop the interchangeable engine turbomachinery. Both contractors will be funded to ensure compatibility of the engines with the common propulsion system components. [148]

All of the above plans were laid out in the JSF EMD Acquisition Strategy document. The JSF Air System and Propulsion System Acquisition Strategies were initially approved by Dr. Gansler on 19 July 2000, which allowed the propulsion RFP to be released. The overall Acquisition Strategy was approved by Dr. Gansler on 8 November, clearing the way for the final CFI release. The JSF Acquisition Strategy was determined to comply with the acquisition strategy guidelines contained in DoD Regulation 5000.2-R. At that point, some issues regarding live fire testing had not yet been resolved.[149] Furthermore, the Congressional delays described in Section 5.1.8 necessitated a revision to the schedule in order to ensure a smooth transition from CDP to EMD, and provide authority for the procurement of long lead propulsion system material to reduce the risk of a six month delay in completing EMD propulsion system flight certification and a consequential delay in EMD flight testing. Bridge contracts were authorized for Boeing,

* USD(A&T) changed its name and responsibility to include logistics in 1999.

Lockheed and Pratt & Whitney. This addendum was approved on 7 February 2001 by [redacted] the USD(AT&L) Principle Deputy, who was acting after Dr. Gansler left with the Clinton Administration.[150]

5.5.3 Avionics Architecture Development

Since the development of the airborne radar in World War II, avionics has grown steadily in prominence not only as a factor in the combat effectiveness of airborne weapon systems, but also as a contributor to LCC. Avionics has increased steadily as a percentage of unit flyaway cost. Avionics supportability and the requirement for periodic upgrading to keep pace with evolving threats and missions are important LCC elements. This contribution increases with airframe life. A key goal of avionics investigations during CDP is to arrive at avionics concepts for lethal, survivable JSF platforms while controlling both absolute avionics cost and the avionics fraction of system LCC. Figure 61 portrays graphically the functions that a typical JSF avionics suite must perform. The JSF concept envisions integration with the DoD System-of-Systems (SoS) network to a degree unprecedented for strike aircraft.

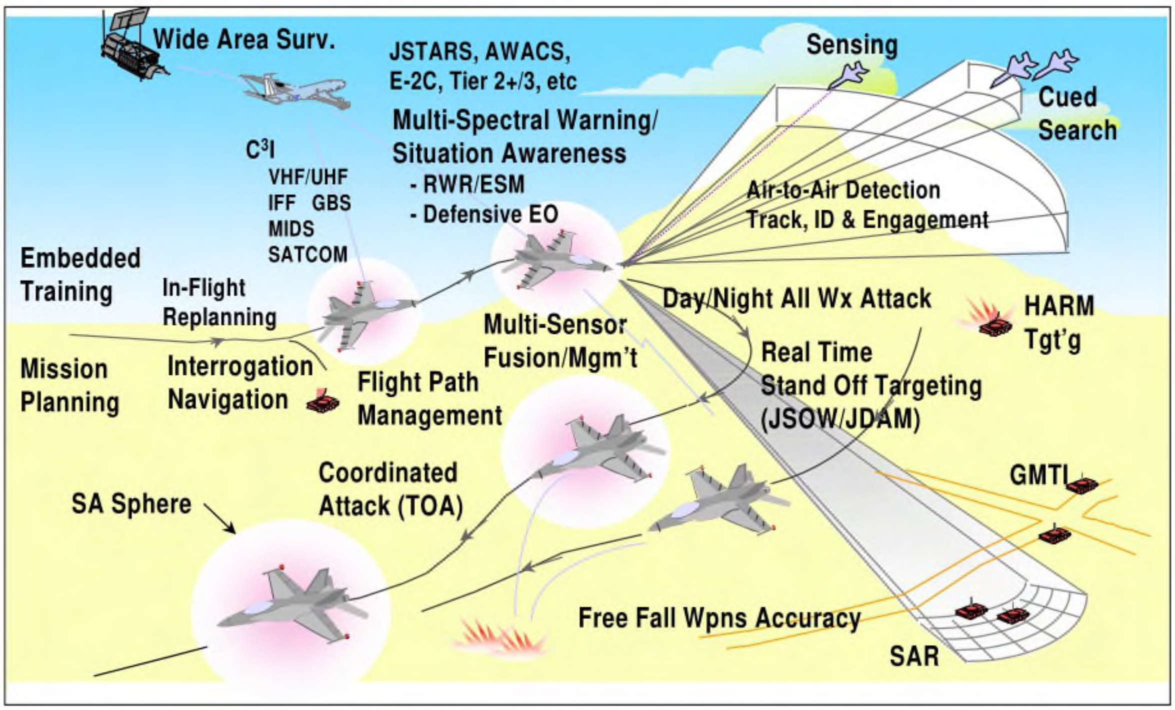

Figure 61: JSF Notional Avionics Functions

During 1998-1999, the Mission Systems IPT completed the third iteration of the JSF Avionics Architecture Definition (JAAD), previously discussed in Section 3.3.5. JAAD 3.0, released on 4 October 1999, reflects the results of activities under the ongoing JSF CDP and supporting programs such as the Integrated Core Processing (ICP) technology demonstration, Software Infrastructure Technology Maturation (SITM), Multifunction Integrated RF System (MIRFS), and Integrated Sensor System (ISS). JAAD 3 confines itself to requirements issues, especially the attributes that the JSF Mission Systems must possess to meet overall weapon system requirements, and contains no design particulars. The JAAD was developed in conjunction with both WSCs and consequently excludes any competition sensitive details, but proprietary annexes were prepared by each WSC. JAAD 3 serves as a vehicle for refining and achieving consensus on the architectural attributes and standard evaluation factors to be incorporated into EMD preparation. It also provides a consistent framework for identifying and resolving issues associated with open systems practice and application of standards to JSF Mission Systems, as well as facilitating interaction between the JSF PO and the contractors in support of government insight into the status of

evolving avionics concepts. Both WSCs agreed upon and endorsed the following eight architecture attributes:[151,152]

1. **Partitioning and interfaces for openness:** An “open system” is defined to be one that is designed and implemented in such a way (a) that the hardware and software can be supplied by any organization having the requisite capability, and (b) system elements from multiple sources can be readily integrated to achieve the required ensemble of capabilities.
2. **Controlled coupling among system elements:** The architecture must incorporate an interconnection fabric, which allows all appropriate interactions among functional entities.
3. **Scalability and evolvability:** The performance increases or decreases commensurate with the number of hardware and software modules, and changes to the number of modules has a minimal impact on the rest of the system.
4. **Functionality as a node in a system-of-systems (SoS) network:** The avionics must provide an efficient and flexible basis for implementing the communications, information processing, display, and other functions associated with current and future interactions with other systems and the support infrastructure.
5. **Technology independence and parts obsolescence mitigation:** The avionics must not depend on particular technologies or specific products, which may not be available throughout the life of the system. The architecture will facilitate the selective and localized replacement of components that are no longer available.
6. **Support for system-level reliability and maintainability:** The avionics must have high levels of intrinsic reliability, PHM functionality, maintainability and graceful degradation without incurring excessive cost or technical risk.
7. **Guaranteed timing and real-time execution:** Timing constraints must be confined within the partitions such that critical timing parameters (and effects of changes to timing) in one partition do not adversely affect operations within another partition. Timing must be controlled so the sequence and duration of critical task execution is reliable and predictable.
8. **Information assurance and protection:** The avionics architecture must incorporate affordable hardware and software security features.

The JSF avionics architecture is grounded in the application of open system principles. The motivations of interoperability with other systems and supportability over an operational lifetime spanning many generations of technology apply with special force to the JSF. Open systems methodology involves functional partitioning and mapping of requirements onto functional entities that may then be implemented with various combinations of hardware and software.

The JSF family of platforms requires an avionics suite which can be tailored while retaining the greatest feasible commonality across configurations, remaining compatible with each owning service’s support environments, and maximizing affordability for all system users. Similarly, anticipated export of JSF aircraft requires the ability to selectively add or remove functionality to comply with technology releasability criteria. To satisfy these needs, the JSF architecture and implementation must be highly modular so that specific functions or capabilities are encapsulated in discrete entities. Similarly, the system support environment must have the capability to integrate specified configurations, made up of desired functional modules, with assurance that only desired functions are incorporated or disclosed.[153]

The continuing evolution of JSF avionics concepts and the JAAD will be based on a wide range of data sources, especially the results of technology demonstrations and virtual engineering work which define avionics functions and quantify their cost and contribution to system effectiveness. The final architecture will incorporate a set of modular avionics functions, with their associated implementing technologies,

which have been reduced to an acceptable level of risk through analysis and demonstration and characterized in terms of cost, performance, and technical maturity for use in EMD. For a specific JSF platform, use of the proper mix of avionics modular functions will allow optimization of a specific avionics suite while maintaining maximum commonality across systems. These "building blocks" will include:

- Digital information processing hardware and software
- Software design and support environment
- Information transfer network structure and protocols
- Sensors and sensor management functional areas
- Cockpit/avionics integration
- Weapons integration and targeting
- Electrical power distribution and mechanical aspects of avionics, including packaging and thermal management techniques

Accompanying the building blocks will be a set of "building codes" in the form of interface definitions, design practices, and overall system attributes which will create a framework within which open, competitive, and upgradeable system designs can be implemented. This approach supports DoD acquisition policy and establishes the foundation for a JSF weapon system family that will be affordable and can be updated to meet operational needs over the JSF service life.[154]

5.5.4 Supportability Planning

As discussed in Section 5.1.1, the Supportability Directorate was established in September 1997 with Col [redacted] USMC as the director. The directorate evolved from the Supportability and Training IPT, led by [redacted] who became the deputy director of the Supportability Directorate. In March 1999, the Supportability Requirements division was absorbed, which initiated the evolution into the Autonomic Logistics (Auto Log, or AL) Directorate. Responsible for defining the maintenance and training system strategy for JSF, the main focus of the AL Directorate is to identify, evaluate, and incorporate emerging technologies that significantly reduce support and training life cycle costs. Primary areas of focus are: logistics planning; supportable low observables (SLO); training, reliability and maintainability engineering; propulsion supportability; and the JSF Paintless Aircraft Program (JPAP).

As mentioned in Section 5.1.1, Dr. Scheuren initially led the JAST Directorate from his position at DARPA. With his departure from the program in July 2000 to assume full-time responsibilities for DARPA programs, JAST, which had previously been diminished to an IPT, was dissolved. CDR [redacted] led the Advanced Technology Insertion (ATI) IPT within the Autonomic Logistics Directorate through September, at which time the ATI IPT became a sub-IPT of the A&I IPT. Both IPTs were tasked with leading the numerous technology maturation efforts that supported development of the AutoLog concept.

General Kenne also chartered the flag-level Logistics Advisory Council (LAC) in October 1997. The purpose of the LAC is to advise the JSF Program Director and the overall JSF Advisory Group on service support concepts, logistics cost/supportability trades and other matters required to assure logistics requirements meet service needs.

The LAC's first meeting was held 15 October 1997 at the JSF Program Office. General Kenne discussed her expectations of the LAC, i.e., to help guide logistics decisions. The LAC members then received briefs on the JSF Requirements Process, the JSF Support Concept, the purpose of the Maintenance Systems Advisory Panel (MSAP), and other logistics issues. The members also received briefings from the Boeing and Lockheed-Martin JSF Program managers.

The second LAC meeting was convened 11 March 1998. The council received a brief on the JSF logistics vision, including training, propulsion, avionics and other areas that impact the key areas

responsibility for the LAC: reliability, maintainability, supportability and deployability. Additionally, a JSF Program Office and LAC agreement was established.

On September 24, 1998, the LAC met at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The purpose of this meeting was to show the LAC what contributions JPL was making to NASA, and to show how those technologies can make the JSF aircraft less costly, operate more efficiently, and increase safety margins. Specifically, JPL briefed the LAC on how PHM and Autonomic Logistics influence reliability, maintainability, supportability and deployability.

The LAC's fourth meeting was held on 4 March 1999 at the JSF Program Office. The objective of this meeting was to obtain approval for the JORD supportability metrics, support concept plan boundaries and the EMD supportability assessment plan. The members also received briefs on various cost benefit analysis efforts and the support and training efforts of both Boeing and Lockheed Martin.

The fifth LAC meeting was convened 30 June 1999. This meeting was a combined briefing to the JAG and members of the LAC. The participants were briefed on the status of the ORD and the issues surrounding it. The results of ongoing analysis were also presented to the attendees. The combined JAG/LAC also participated in a discussion of various logistics issues that were of critical importance in the development of the JSF support system.

The LAC met again on 6 Oct 1999. The primary purpose of this meeting was to illustrate how various industry "best practices" were currently in use and moreover, how these innovations could be successfully incorporated into the JSF support system. The LAC members were also briefed on the current status of on-going analysis and the current stage of development of the propulsion system for the JSF.

LAC Seven, which was held on 12 May 2000, resulted in a consensus on "boundaries": those items which the Services prohibited the WSCs from changing. This in effect established the limits of the contractors' trade space. LAC Eight too place on 4 Aug 2000. This meeting focused on basing and training. The key topics were to gain a final consensus on the training approach and to discuss issues faced by JSF with respect to basing, for example, environmental issues, operations tempo and Joint operations.

Driven by the need for the Services to prepare the funding request for the next several years, a formal basing and training study was initiated in 2000. The primary objective of the study was to gain agreement among the Services regarding the training and support concept and the feasibility of joint training at a single site for the first two to four years. The main challenges are gaining consensus on a common approach to training and the environmental issues associated with basing a new aircraft.

During the second half of 2000, the first draft JSF Joint System Training Plan (JSTRAP) was also completed and distributed for review and comment. The JSTRAP was developed to identify all Services' life cycle manpower, personnel, and training requirements for the JSF aircraft. It outlined future training requirements and described the methods and media to be used to train JSF personnel to employ, operate, and maintain the aircraft. All levels of training, from basic qualification to advanced and/or specialized training, were included. This foundation laid by the JSTRAP was specifically designed to allow the training system to be updated in a logical manner to reflect new concepts of training and/or new training requirements.[155] The first draft, dated 29 December, was replaced by the second draft, dated 22 February, but officially signed in late March 2001.

5.5.5 Environmental, Safety And Health (ESH) Planning

In 1995, a JSF Environmental, Safety and Health (ESH) government team was formed and began visiting the JSF prime contractor (i.e., the WSC, P&W and GE) sites to review their respective environmental programs and practices. By 1997, the JSF ESH Team had established working relationships with the primes to identify proposed hazardous materials (HAZMAT) to be used throughout the weapon system's life cycle, as well as to integrate a hazardous material evaluation/approval process into their

existing systems engineering processes. In 1997, the JSF sought to leverage existing technology development projects and partner with the Original Equipment Manufacturers (OEMs) to deliver cost effective, non-polluting technologies to the manufacturing floor and the support community. The ESH Team targeted chromium and initiated three projects to address alternatives to hard chrome plating and to chromated primer used on aircraft interior components. The following is a summary of 1997 through 1999 project activity. Follow-on projects have been initiated for 2000 and include evaluation of non-chromated primer under appliqué material and thermal spray on engine and other components. Follow-on projects included evaluation of non-chromated primer under appliqué material, alternatives to cadmium electroplate for field repair and impact analyses for selected technologies. While funded with FY00 dollars, due to contracting delays, the cadmium project will run through the summer of 01.

High Velocity Oxygen Fuel (HVOF) Thermal Spray Deposition: JSF funded an investigation of HVOF as a replacement for hard chrome plating to be used in line of sight applications by depositing hard wear face coating on component outer diameters. HVOF is expected to eliminate the requirement for hard chrome plating at the OEM and restoration at Depots on landing gear pistons, hydraulic actuators, axle journals, and numerous other components. In 1998, applications were identified, specifications written, and sample coupon testing conducted. Landing gear components on the F/A-18, and P-3 aircraft were replaced with treated parts and tested in the fleet environment. In 1999, first phase fatigue tests were completed and a joint test protocol for landing gear was signed. Applications for turbine engines were identified and parts were coated for testing. JSF OEM corrosion and fatigue testing is expected to continue with additional effort on coating validation for hydraulic actuators and helicopter dynamic components. OEM response to date indicates that HVOF will find wide application on the PWSC aircraft and subsystems.

Alternatives to Hard Chrome Plating: In 1998, JSF joined the Hard Chrome Alternatives Team (HCAT) – an international government/industry technical consortium – to find a replacement for hard chrome on small components and tight internal diameters that do not lend themselves to the high temperature thermal spray of HVOF. Promising alternatives identified in 1998-99 included electrospark deposition, non-nickel electroplating and plasma spray, which deposit metal oxides, Tungsten-Carbide/Cobalt and other alloys. A follow-on project is being funded by the joint Department of Defense/Department of Energy/Environmental Protection Agency Strategic Environmental Research and Development Program (SERDP).

Electrodeposited Coating (E-Coat): JSF funded E-Coat testing to replace high volatile organic compound (VOC) chromated epoxy primer on aircraft interior components with a more durable coating. Coated items are expected to remain in place for the life of the aircraft thus eliminating use of chrome VI and high solvent primers and their attendant compliance issues. In 1998, selected aluminum, titanium and steels were successfully E-coated at the Naval Aviation Depot Jacksonville, Florida. Later in 1998 and through 1999, components on the F/A-18, T-45, EA-6B and P-3C aircraft were coated, installed on the aircraft and tested in the fleet environment to determine field performance. Both JSF OEMs were engaged in the validation of this technology in 1999 but due to unacceptably high cure temperatures affecting the fatigue life of aluminum alloys, the project has been placed on hold by the aerospace community, pending reformulation of the coating.

Non-Chrome Primer Under Appliqué: JSF funded a small project intended to supplement earlier work performed by the materials engineering laboratories at AFRL and the Becker Lab at Patuxent River evaluating the performance of appliqué. An overall ESH program goal is to eliminate hexavalent chromium from the JSF life cycle. Non-chrome primers have been performing well as demonstrated by an on-going JGPP initiative. An approved Type II non-chrome was selected for validation under appliqué. Mechanical tests were performed on prepared coupons at the materials lab at the Depot Jacksonville. Corrosion studies are to be performed by AFRL.

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Alternatives to Cadmium Plating: A second regulated material of concern is cadmium. A project was initiated in FY00 assessing field requirements for cadmium in repair of cadmium coatings. Alternatives under consideration include, alkaline Zn-Ni and Sn-Zn electroplating and IVD Aluminum.

Impact Analyses for P2 Technologies: Cost and environmental impact analyses were performed as part of a NAVAIR project. JSF was offered the opportunity to have four of its projects evaluated for return on investment. The studies focused on non-chrome primer for aircraft moldlines, appliqué in lieu of conventional topcoats, HVOF as an alternative to chrome plate for outer dimensions, and cadmium alternatives. All studies indicated a favorable payback and a measurable reduction in hazardous materials/waste.

ESH planning: An Environmental Assessment (EA) was begun in 1998 for CDP Flight Test Program to identify any problems and compliance issues with basing and flight testing JSF aircraft at government facilities. The final EA for Edwards AFB was completed in September of 2000. A Finding of No Significant Impact (FONSI) was signed on 14 September 2000. The EA for NAS Pax River was completed in July of 2000 and the FONSI was signed by MGen Hough and Capt Hovatter (CO, NAS Pax River). An EA is also planned for the EMD Flight Test Program. Prior to source selection, the ESH Team worked with the WSCs in identifying and analyzing the use of HAZMAT in the CDA and PWSC designs. This collaboration will be useful as the PWSC develops a Hazardous Material Management Plan. ESH Team members have been placed on the Criteria Subcommittee of the Basing WIPT, and tasked with ensuring that environmental criteria, which may influence training base selection, are included in the evaluation of potential bases. These criteria have been incorporated and base evaluations are set to begin in the spring of 2001. Down select of both pilot and maintenance training sites will occur during the early fall of the year. Preliminary assessments will be done by the contractor to determine potential impacts associated with air pollutants, aircraft noise, and the ecological environment. This information will feed into later Environmental Assessments and Environmental Impact Statements.

ESH Activities: The JSF ESH Team has participated in various activities, either in support of program initiatives or sponsored by it. Team members were part of a carrier familiarization trip (USS Enterprise, March 2000) during which flight and carrier operations were seen first hand to get a full understanding of the challenges faced by the Fleet. Additionally team members have played an active role in numerous ACQ ESH Workshops (late 2000, early 2001), which intended to find better ways of institutionalizing the ESH requirements of the DoD 5000 series in to the acquisition process. The workshop included a DUSDES brief to further promote these proposed improvements. The ESH Team is leading an effort to acquire environmental data for Aircraft Maintenance in the Air Force. The goal is to populate the Environmental Life Cycle Cost Model, which has been previously validated with Navy data, to then utilize the Model as a tool for the JSF. The JSF ESH Team is maintaining and updating a database that relates technology development projects with the impacted materials and processes as constrained by environmental and safety regulations and standards. The ESH Team also periodically attends DoD/Service specific P2 conferences, CVNX (future carrier program) meetings to assess JSF carrier suitability issues and holds biannual core team meetings.

5.6 Summary of Concept Demonstration Phase Through December 2000

December 2000 is approximately five-sixths of the way through the CDP of the JSF Program. This phase includes flight demonstration of the CDAs by Boeing and Lockheed Martin, refinement of their PWSC designs, continuing Technology Maturation activities and requirements development, as well as primary and alternate propulsion system development. The CDP acquisition strategy has the following elements:

- Demonstrate the viability of a multi-service family of variants

- Maintain a competitive environment up to EMD by flight demonstrations of two different STOVL approaches and two different aerodynamic configurations
- Provide for affordable requirements trades throughout the CDP
- Provide for affordable transition of low-risk technologies into EMD, with moderate integration risk
- Prepare for the introduction of a competitive alternate engine in the JSF Production phase

Thus far in CDP, both WSCs have had successful CTOL flight demonstrations and are well on their way to demonstrating the objectives of the flight test program. Both WSCs are preparing to begin STOVL flight testing as well. Pratt & Whitney has also completed significant testing of the CDA propulsion systems.

The JSF Program Directorship changed for the third time, demonstrating the viability of the program's innovative approach to joint management. The JSF Program has maintained strong Congressional support for the current phase. Nine international partners have joined the program, and several other nations have expressed interest. Activities in several areas—technology demonstrations, requirements, supportability, program management, and weapons system concept demonstration—are underway, and will lead to the most significant program events during the remainder of CDP.

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[15] Office of the Under Secretary of Defense for Acquisition and Technology, "Report of the Defense Science Board Task Force on Acquisition Reform Phase IV Subpanel on Research and Development," July 1999.
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6 Weapon System Concept Development and Demonstration

The following sections contain descriptions of some of the activities of each of the prime contractors through the end of 2000. It should be noted that many activities took place, including (but not limited to) manufacturing preparations, subcontracting with vendors, concept-unique technology demonstrations (as well as WSC participation in many of the JSF generic Tech Mat efforts), and continuing PWSC design evolution. As discussed in the previous chapter, JSF awarded The Boeing Company and Lockheed Martin Corporation 51-month contracts for the Concept Demonstration Phase on 16 November 1996. The McDonnell Douglas team, including the individual McDonnell and Northrop designs, is included for reference.

6.1 McDonnell Douglas/British Aerospace

The McDonnell Douglas/British Aerospace team (MDA/BAe) began their involvement in the JAST program by evaluating over forty aircraft concept configurations from the following areas: multiservice, supportability, low observables, low observables/commonality and carrier suitability. Generic planforms examples for some of these are illustrated in Figure 62. From those 40+ concepts, MDA/BAe selected a primary and an alternate design to focus on (the primary is the aircraft depicted on the bottom right, and the alternate on the bottom left of Figure 62).

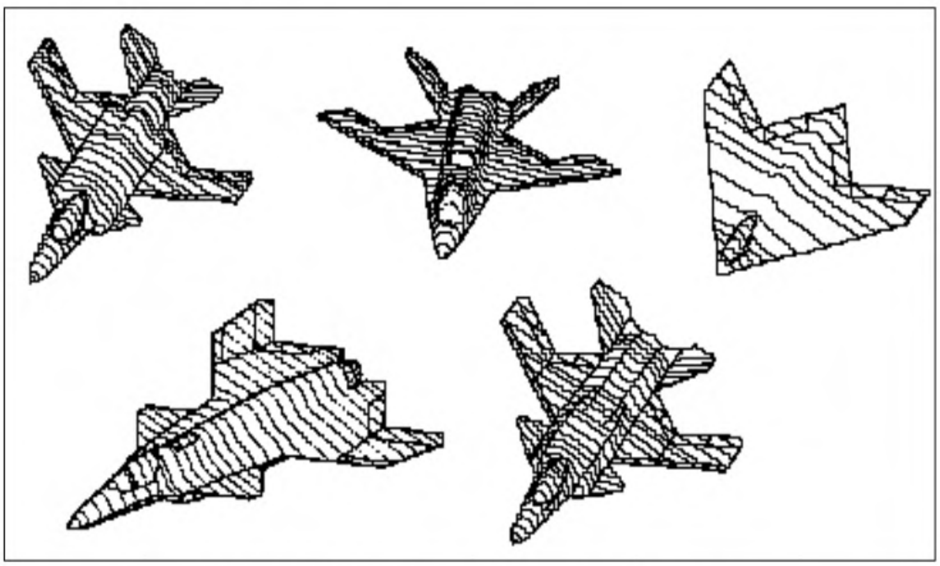

Figure 62: MDA/BAe Concept Study Areas.

The MDA CALF[*] aircraft design utilized a modified General Electric F120 engine, with a portion of the exhaust gas ducted forward to drive a lift fan via a turbine. The primary cruise nozzle would be blocked off during hover, and the portion of the main engine exhaust not used for the lift fan would exit through two lift nozzles on the lower fuselage. When designing their JAST concept, the MDA/BAe team decided to utilize the same propulsion concept.

[*] The DARPA Advanced Short Takeoff, Vertical Landing (ASTOVL) Program was known as the STOVL Strike Fighter (SSF) Program (1988-91) and the Common Affordable Lightweight Fighter (CALF) Program (1992-94). The contractors' concepts were referred to by any or all of these names, usually depending upon when each contractor became involved in the program. The ASTOVL efforts are described in more detail in Appendix A.

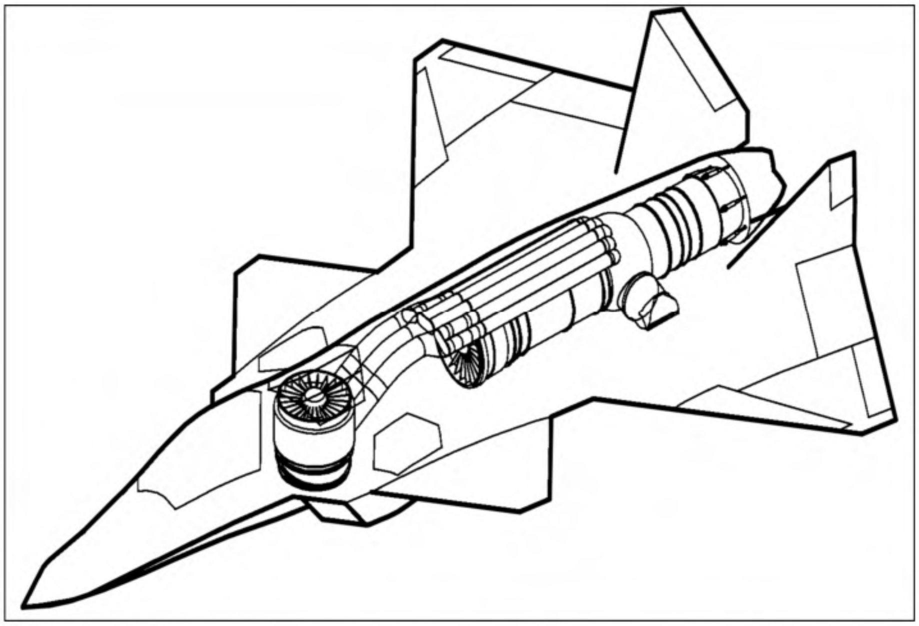

Figure 63: GCLF Positioning Within an Early MDA/BAe SSF/JAST Design.

The MDA/BAe ASTOVL aircraft was relatively large, since the Gas Coupled Lift Fan (GCLF) system (shown in Figure 64) did not add as much concentrated weight as a Shaft Driven Lift-Fan (SDLF) or a lift engine, but required more volume for the ducting of engine gas forward to the lift fan.

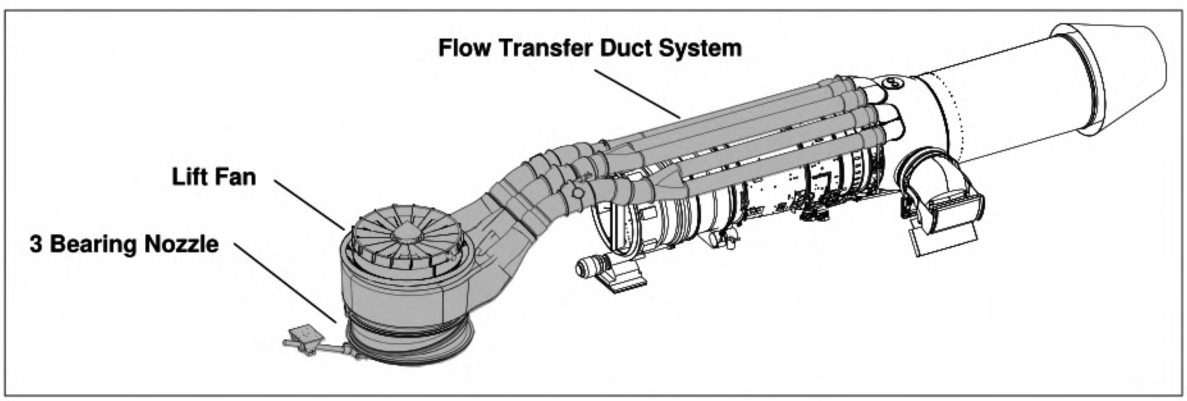

Figure 64: GCLF Powered Lift System.

The wing of the MDA/BAe aircraft was diamond-shaped, with relatively large canards for pitch control and two small, canted vertical fins for directional stability and control, supplemented by multi-axis (pitch and yaw) thrust vectoring. As the MDA/BAe PWSC design evolved it became reminiscent of the MDA X-36 Unmanned Aerial Vehicle (UAV) which the MDA Phantom Works had designed and built just a few years earlier.

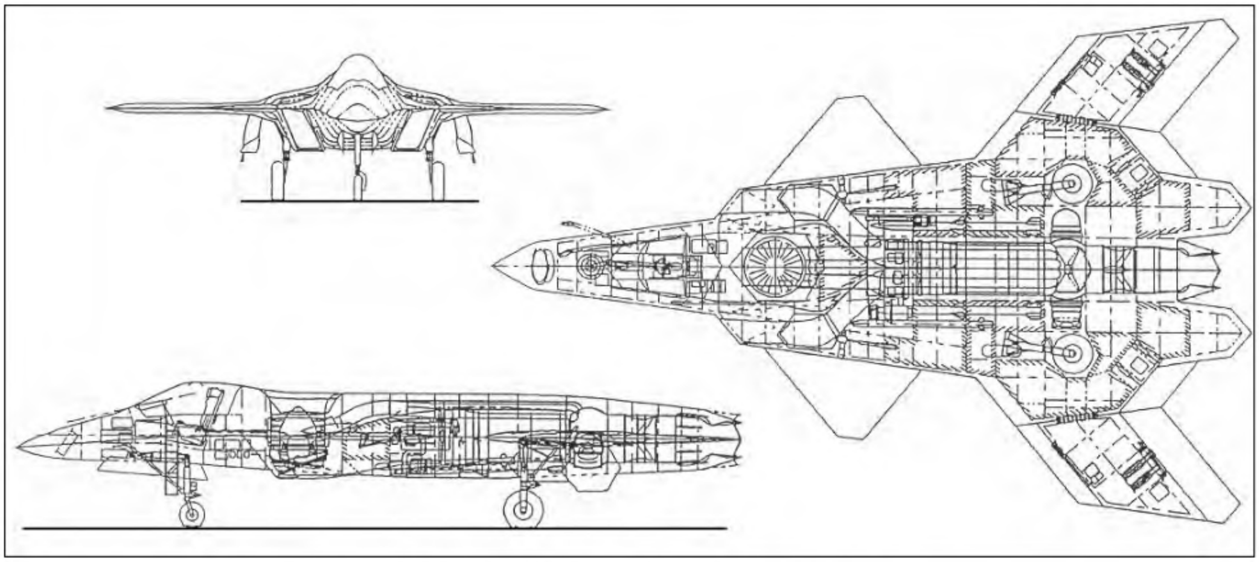

Figure 65: MDA STOVL JAST 1 Concept.

As work on the MDA/BAe design progressed, more planform variants were studied. Some of the MDA/BAe JAST variant families shared a common center fuselage but different wings. This is illustrated in Figure 66 where the CTOL and CV variants appear to be identical, but the wings on the STOVL variant have been replaced with shorter, clipped wings.

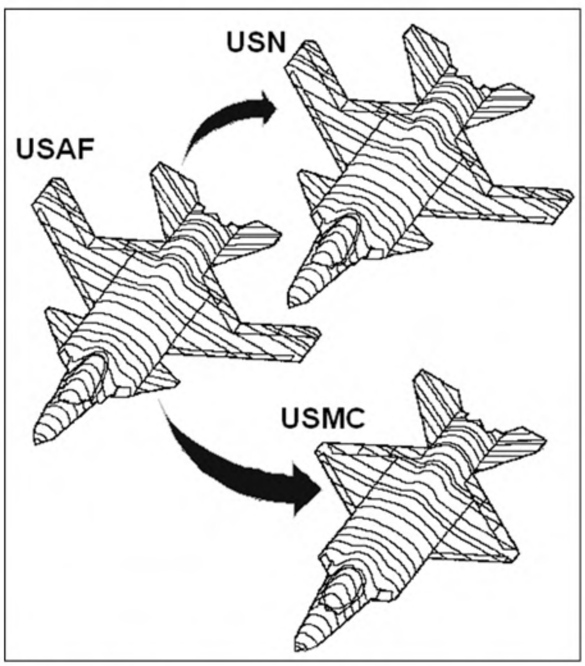

Figure 66: MDA/BAe JAST 2 Design Commonality.

The final McDonnell Douglas PWSC JAST design prior to the teaming with Northrop Grumman was known as JAST-2. An overview of the early concept design evolution is given in Figure 67.

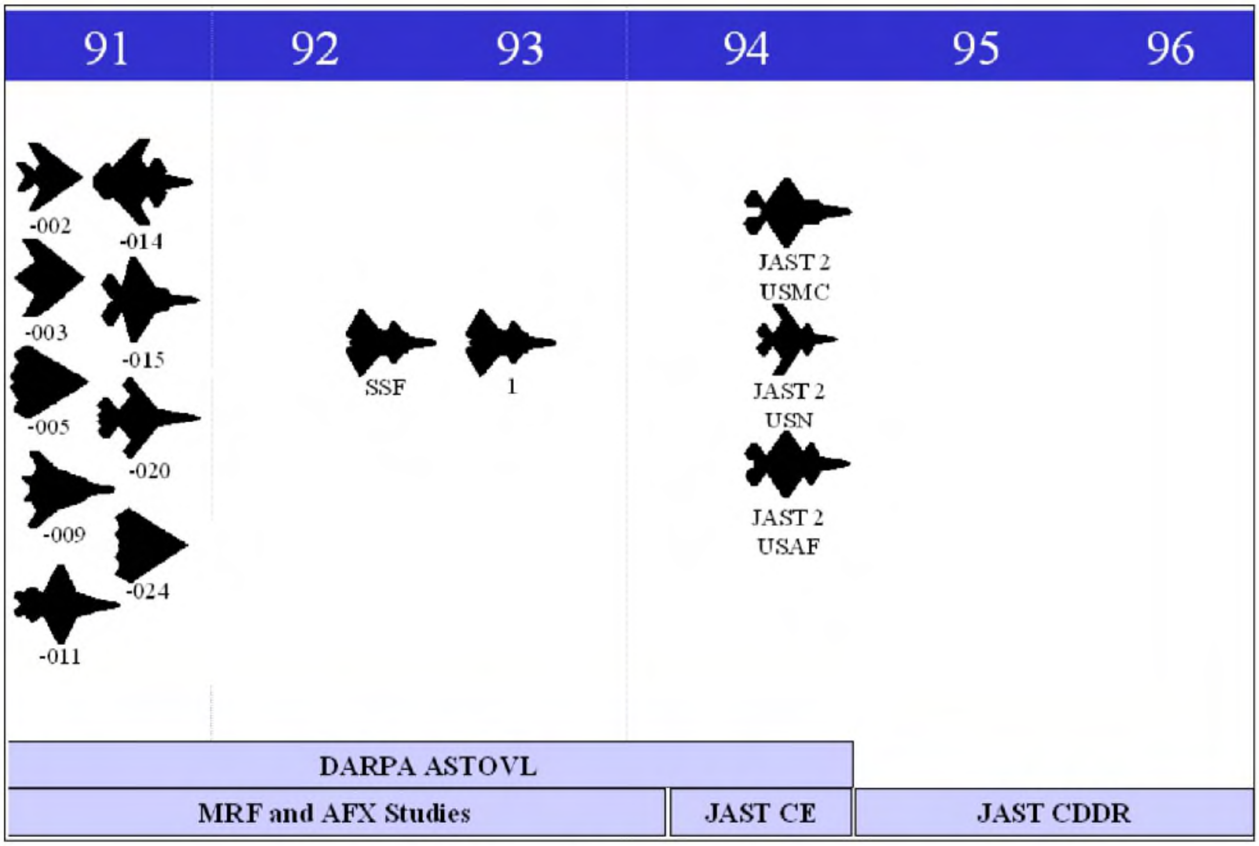

Figure 67. McDonnell Douglas concept evolution.

6.2 Northrop Grumman

The Northrop Grumman JAST design evolved out of their work in the CALF program. The Northrop Grumman JAST team took the CALF concepts, weighed requirements sensitivities and trade studies, then conducted a number of commonality studies and settled on three aircraft concepts.

In designing their tri-service modular design, Northrop Grumman initially designed two aircraft. One was a naval (CV) variant and was identified in the TSC-1 and TSC-2 designs. The STOVL and CTOL requirements and approaches were addressed in the TSC-3 design. The first, known as Tri-Service Commonality* 1 (TSC-1), was a direct evolution of their CALF design (Figure 68). The TSC-1 had a common center fuselage, aft fuselage, empennage, engine, crew station and avionics core. The Northrop Grumman ALF-12F5 configuration evolved into the TSC-2 and TSC-3 designs. The TSC-2 design was approximately 75% common across the services, TSC-3A was approximately 90% common.

* TSC was an internal designation created by Northrop.

Figure 68: Northrop Grumman CALF/TSC-1 Concept

Following more studies, Northrop Grumman selected the TSC-3 design as their PWSC. Modifications to the TSC-3 design were made and the new design became known as the TSC-3A.

The TSC-3A design was capable of carrying Joint Direct Attack Munition (JDAM) weapons internally, had an increased wing area and aspect ratio over the ALF-12F5 concept and was designed to use an axisymmetric nozzle.[1] The fixed vertical fin on the TSC-3A was smaller than that of its predecessor and also had a trailing edge extension. The TSC-3A had an optional gun as well as multi-purpose, low observable wing-tip pods for air-to-air (A-A) weapons carriage (see Figure 69). Northrop Grumman's TSC-3A STOVL design employed a lift engine for vertical lift. A single vertical tail provided directional stability and control. The wing was designed to meet the ASTOVL 24,000 lb empty weight limit.

The TSC-3A CTOL design, with payload, was designed to have a mission radius of 825 nautical miles (nmi); with external fuel tanks the aircraft would have been capable of just over 1,000 nmi.[2] The TSC-3A design had a wingspan of 35 feet, a length of 49 feet 11 inches and a height of 14 feet 6 inches. The wing area on the STOVL and CTOL versions was 490 sq. ft.[3]

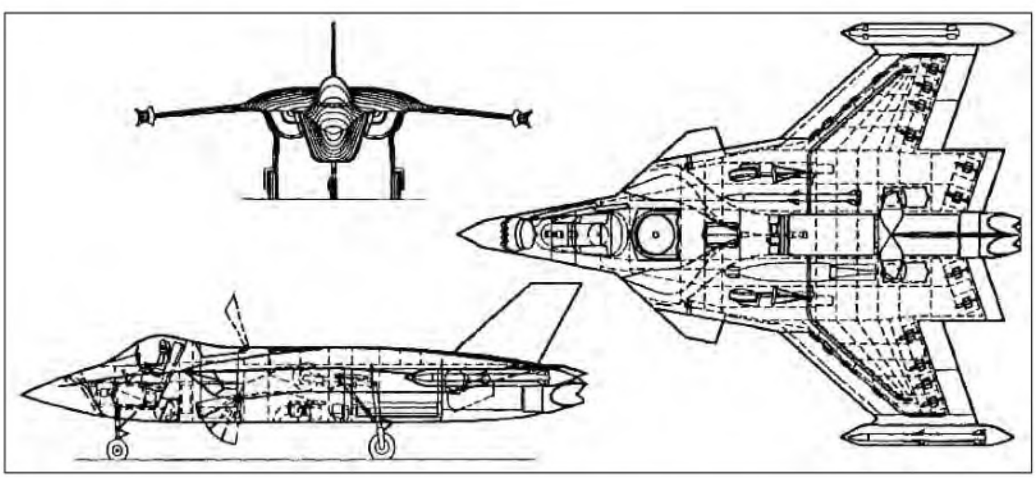

Figure 69: Northrop Grumman STOVL TSC-3A Three-View Drawing

The airframe of the TSC-3A would have largely been manufactured of composite materials. The control surfaces, cooling ducts, inlet ducts, radome, skins and doors would have all been made of composite materials, comprising 29.4% of the aircraft.[4] Other large sections of the aircraft, such as the wing and the forebody would also have been made from composites. Titanium and aluminum would have also been used in the construction of the aircraft.

Figure 70: Northrop Grumman JAST TSC-3A STOVL PWSC

The primary propulsion system for the TSC-3A would have been a derivative of the P&W F119 with a modified inlet case, modified software, a pitch/yaw axisymmetric nozzle and a STOVL exhaust module consisting of a flow blocker/remote augmentor and a STOVL valve with dual offtakes.[5] The lift engine selected was a Rolls Royce PSE78 (see Figure 70). For wing-borne flight, small "hammerhead" canards in combination with control surfaces at the aft end of the aircraft provided pitch control. An overview of the early concept design evolution is given in Figure 67.

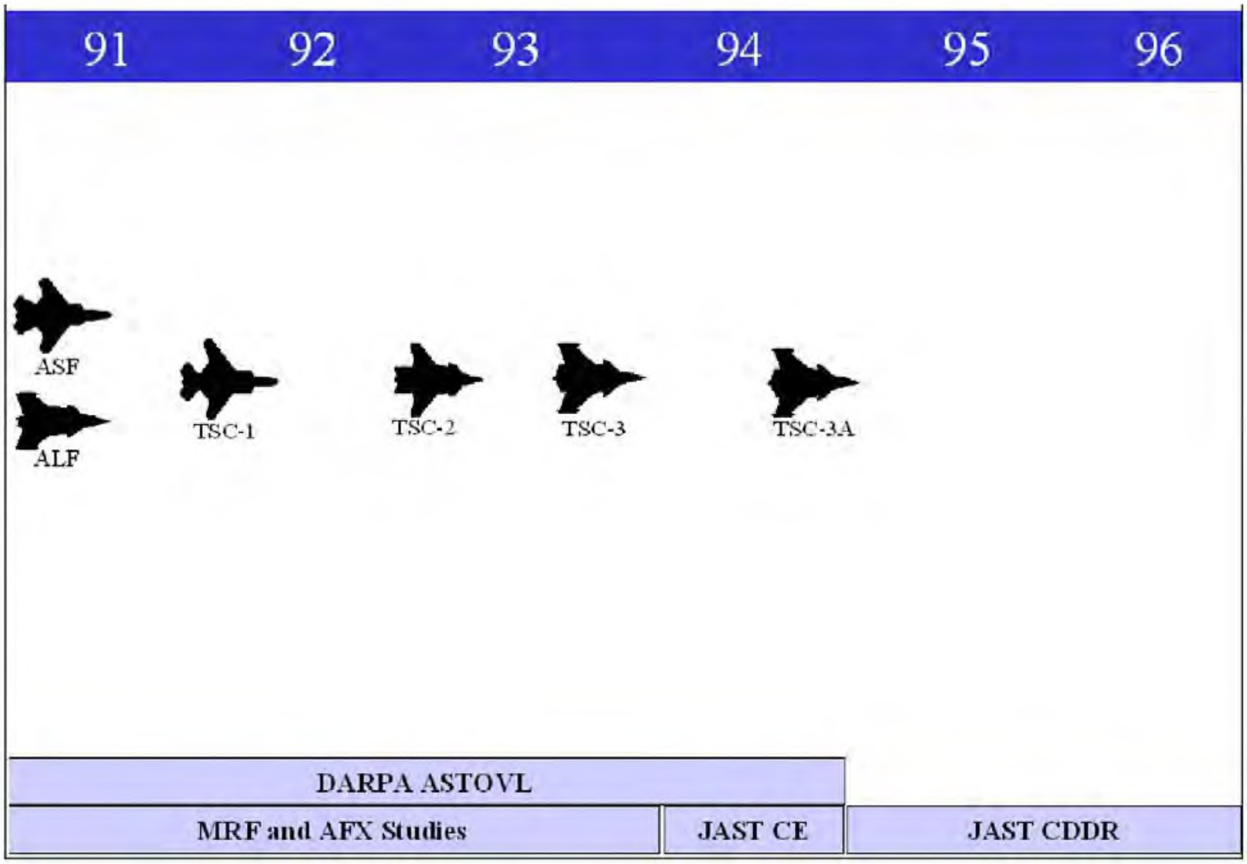

Figure 71. Northrop Design Evolution.

6.3 McDonnell Douglas / Northrop Grumman / British Aerospace

When McDonnell Douglas, Northrop Grumman and British Aerospace joined forces to compete for the JAST contract, McDonnell Douglas led the team. The contractors quickly surveyed their design options and chose the path for their PWSC, The contract awards were in December 1994 and the PWSC was selected in June 1995. The MDA/NGC/BAe design philosophy was primarily measured for CTOL (propulsion, acceleration, maneuverability, etc.) and modularized for STOVL, CV.

While in the process of selecting their PWSC design, the MDA/NGC/BAe team considered the JAST 1-5 concepts, which were evolved from the Northrop and MDA/BAe work during ASTOVL, MRF, SSF and JAST.[6]

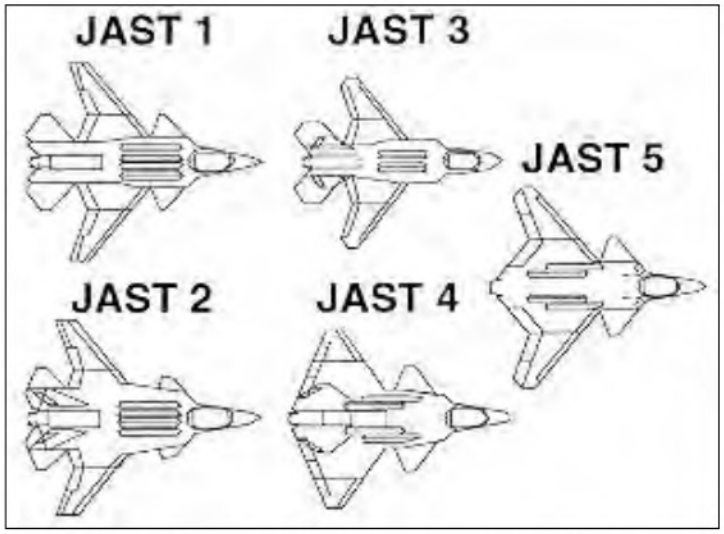

Figure 72: MDA/NGC/BAe JAST 1-5 Concepts

The MDA/NGC/BAe team combined the best attributes of these designs and matured them into two new PWSC candidates. The JAST 1-3 designs evolved into the JAST 6 (wing, body tail) family and the JAST 4 & 5 designs evolved into the JAST 7 (tailless) family (Figure 72 and Figure 73). JAST 6 merged the JAST 1 fuselage with the JAST 3 wing carry-thru and aerodynamics. JAST 6 had a modular weapons bay and lift system. JAST 7 merged the JAST 4 STOVL integration with the aerodynamics of JAST 5. A large number of trade studies were conducted between March and May 1995 and the JAST 6 and 7 configurations were stabilized. As of the summer of 1995, the MDA/NGC/BAe team was still considering the GCLF and L+L/C propulsion systems and both JAST 6 and JAST 7 were designed with each propulsion system installed.[7]

The MDA/NGC/BAe team considered four vertical lift propulsion systems, a shaft driven lift fan (SDLF), direct lift (DL), GCLF and L+L/C. The choices were narrowed down to two as the SDLF and DL concepts were discarded. The positive attributes of the GCLF were its extensive risk reduction during the ASTOVL program, and better up and away performance. Its negative attributes included its large size, adverse temperature ranges and pressure environments for the ducts, and the required cost of engine development for higher airflow. The positive aspects of the L+L/C system included the high amount of commonality between the STOVL and CTOL variants, decoupled technical and cost risks of the STOVL and CTOL variants, the L+L/C engine had the greatest growth capability and the L+L/C system utilized a near off the shelf cruise engine. The negative attributes of the L+L/C system included the development of a new lift engine, no full scale lift engine available for concept demonstration and the impact of a second dissimilar engine.[8]

Following more cost and trade studies and configuration maturity, the team selected the L+L/C concept. Some of the reasons for the rejection of the GCLF concept included: Large volume required for the duct system; this increased cross sectional area (supersonic drag) and added to the size, weight, and complexity of the fuselage and wing carry-through structure. Survivability concerns related to the hot, high-pressure ducts in close proximity to fuel tanks, hydraulics, and other systems. Vertical landing would not be possible if there were a leak in the duct system when returning from a mission.

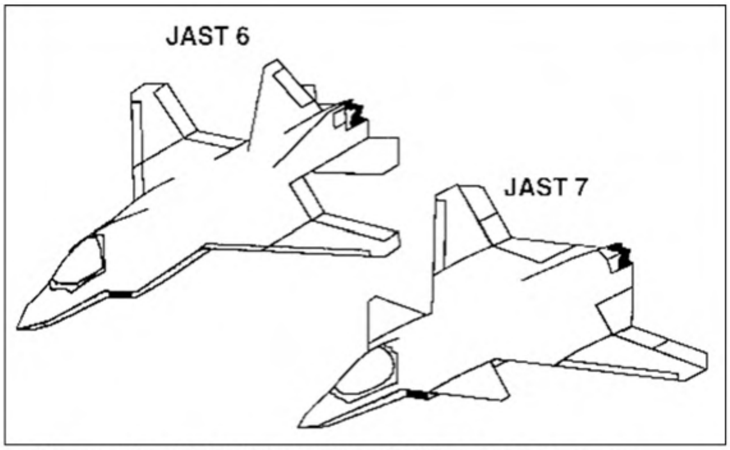

Figure 73: MDA/NGC/BAe JAST 6 & 7 Concepts

By mid/late 1995 the MDA/NGC/BAe team was focusing on an airframe with four tail surfaces and a separate lift engine located behind the cockpit.

It should be noted that some X-36 Tailless Fighter Agility Research Aircraft (TFARA) experience and knowledge was being incorporated into the team design. While some of the McDonnell Douglas designs were clearly derived from the X-36, its influence was seen in the JAST 10 design as shown in Figure 74.

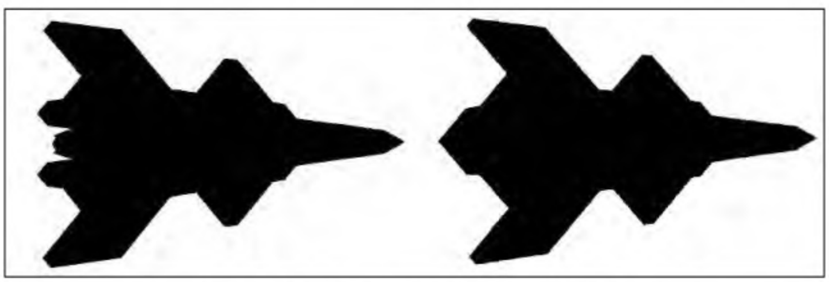

Figure 74: JAST 7 (left) and X-36 (right).

Compared to Northrop's L+L/C JAST design, the new MDA/NGC/BAe PWSC design had a larger-span, "lambda-shaped" wing for improved up-and-away capability. The aft pitch control surfaces—which on Northrop's design were just flaps on the aft fuselage "deck"—were enlarged, becoming more like ordinary tail surfaces, this was known as a 6-tail design and is illustrated in Figure 75. Subsequently, both the canards and the vertical tails were removed, while the horizontal tails were canted into a shallow "V" to provide, in combination with multi-axis thrust vectoring, stability and control in both the pitch and yaw axes. The tail configuration went through several iterations and strongly resembled the tail found on the Northrop / McDonnell Douglas Advanced Tactical Fighter YF-23 aircraft.

Figure 75: JAST 9B Artist's Rendering

The final MDA/NGC/BAe PWSC design, known as JAST 10, evolved from the JAST BAA 94-1 and DARPA ASTOVL studies. Each approach was assessed through design and analysis trade studies to determine the best approach for providing an affordable and effective aircraft.

The MDA/NGC/BAe PWSC service variants had only minor differences in the outer mold line. The larger outer wing panel and inner wing leading and trailing edge extensions would have allowed the CV configuration to meet the carrier suitability standards while maintaining a high part commonality to the CTOL variant. For the STOVL configuration, a lift plus lift cruise concept was used with the lift engine behind the cockpit and between the inlet ducts. As discussed earlier, the aft lift module would have blocked blow thru the cruise nozzle and directed it to the two lift nozzles.

JAST 10 was a "near-tailless" single engine concept with a bifurcated inlet and a low observable axisymmetric exhaust nozzle. The aircraft was designed with the weight, performance and signature advantages that are inherent in an aircraft without a vertical tail. The canted tails were designed as two large moving tails with a surface area of 50.8 square feet each. The tails were designed with a 25º anhedral to provide for directional stability; multi-axis thrust vectoring would have been used to enhance directional control.[9]

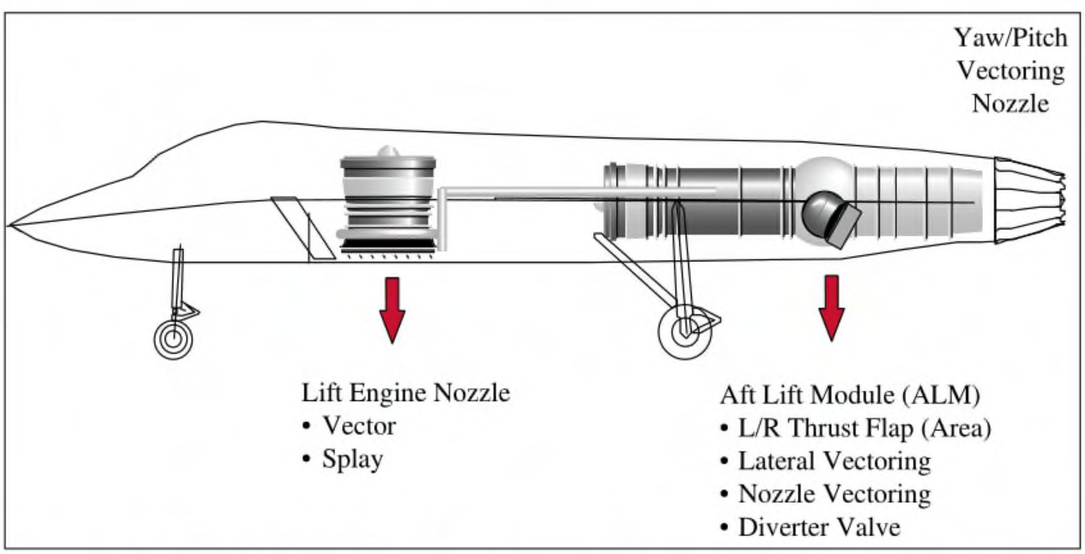

Figure 76: MDA/NGC/BAe L+L/C-Powered Lift Control System

STOVL capability was designed to be provided by a "three post" L+L/C concept. While performing vertical landings and short takeoffs, the JAST 10 would have used a combination of a single GE/Allison GEA-F320L2 lift engine and an aft lift module (ALM). The ALM consisted of two principal components, a diverter valve to switch the cruise engine between STOVL mode and cruise mode configuration, and the rear lift nozzles that would have provided the thrust and control functions when the cruise engine was operating in STOVL mode and fan duct sealing during cruise mode. In STOVL mode, the diverter valve would have closed the cruise exhaust system and opened a passageway allowing the core and fan streams to enter the rear lift nozzles. The nozzles would then control the engine operating line and vectored the thrust as required for control during STOVL activities. When in cruise flight, the engine exhaust would be directed through a yaw/pitch LO axisymmetric nozzle (Y/PLON) on all three PWSC variants.

The planned ASTOVL Program risk reduction phase had included near-full-scale powered model tests to verify the performance of each contractor's proposed powered-lift system. Accordingly, Lockheed, Boeing, and McDonnell Douglas had Large Scale Powered Models (LSPMs) under construction at the time the ASTOVL program was merged with JAST.

The aircraft designs were still evolving after the LSPM construction was underway. McDonnell (as well as Boeing and Lockheed) therefore tested small scale powered models (SSPMs) that matched the LSPM configurations as closely as possible. This direct small-scale to large-scale comparison allowed the best possible estimates of scaling corrections that would have to be applied to future small scale test results. Subsequent configurations could then be tested at small scale with greater confidence than otherwise possible.

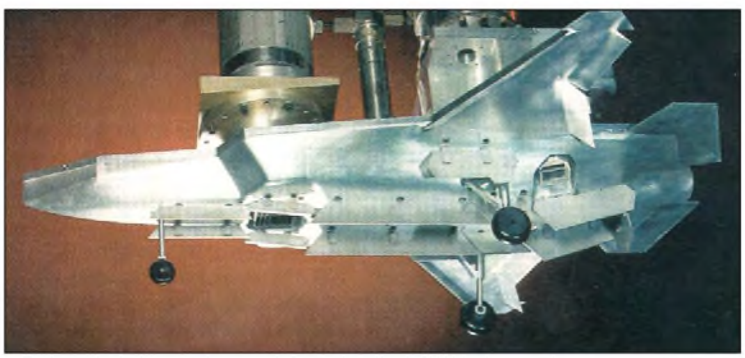

Figure 77: MDA/NGC/BAe SSPM Shown Deployed Lift Improvement Devices

The MDA/NGC/BAe team did not test a complete LSPM. When the team abandoned the Gas Coupled Lift Fan in favor of a lift engine, work on MDA's LSPM was discontinued since it was no longer relevant to their selected concept. Full-scale propulsion system testing using a YF120 engine and a lift fan using F101 components was conducted, however, and experience with the aft lift module consisting of the diverter valve and the aft lift nozzles was directly applicable to their L+L/C concept.

Northrop never had an LSPM, because of funding constraints, since they were only participating in ASTOVL through a no-cost contract. Furthermore, LSPM testing was not as relevant to the particular risks associated with the L+L/C concept as it was to the other concepts. Most of the risk with L+L/C lay in the development of the lift engine. While there was a high probability that such development could be accomplished successfully, it would require time and funding, and problems could be expected along the way (as in any new engine development). If an LSPM were tested in the 1995 timeframe, it would have to use a lift engine adapted from test assets readily available in the near term, which would do little to mitigate the development risks for the "real" lift engine.

In 1994, MDA began construction of their GCLF LSPM propulsion system at GE's Peebles, Ohio test facility. The engine with a slave nozzle was first run in February 1995. After 22 hours of check-out and calibration tests, the bifurcated air induction system and the lift fan were installed in March for a further 9 hours of tests, which concluded in May 1995. The test rig with the inlet system is shown in Figure 78; the lift fan inlet is covered with screens to prevent anything falling or getting sucked in. Although the lift fan concept was dropped, the duct blocker/lift nozzle feature was maintained in the L+LC design. It would have been a GE/Allison built Aft Lift Module between the P&W engine and the P&W nozzle. The LSPM airframe was also never completed, due to the change in STOVL concept.

Figure 78. MDA LSPM

Interestingly, the MDA/NGC/BAe team calculated that the separate lift engine offered the potential for a "get home" capability in the event of a main engine loss. MDA/NGC/BAe planned to demonstrate this capability during flight-testing. Additional design features included: off-the-shelf F119 cruise engine (except for the nozzle) on all variants; General Electric/Allison lift engine design of approximately 16,000 lb thrust on STOVL variant; expandable weapons bay on the Navy variant to allow internal carriage of two 2,000-lb class weapons plus air defense missiles while other variants carried two 1,000-lb weapons plus air defense missiles internally; no vertical tail; directional stability and control provided by the shallow "V" tail in combination with multi-axis (pitch/yaw) thrust vectoring.

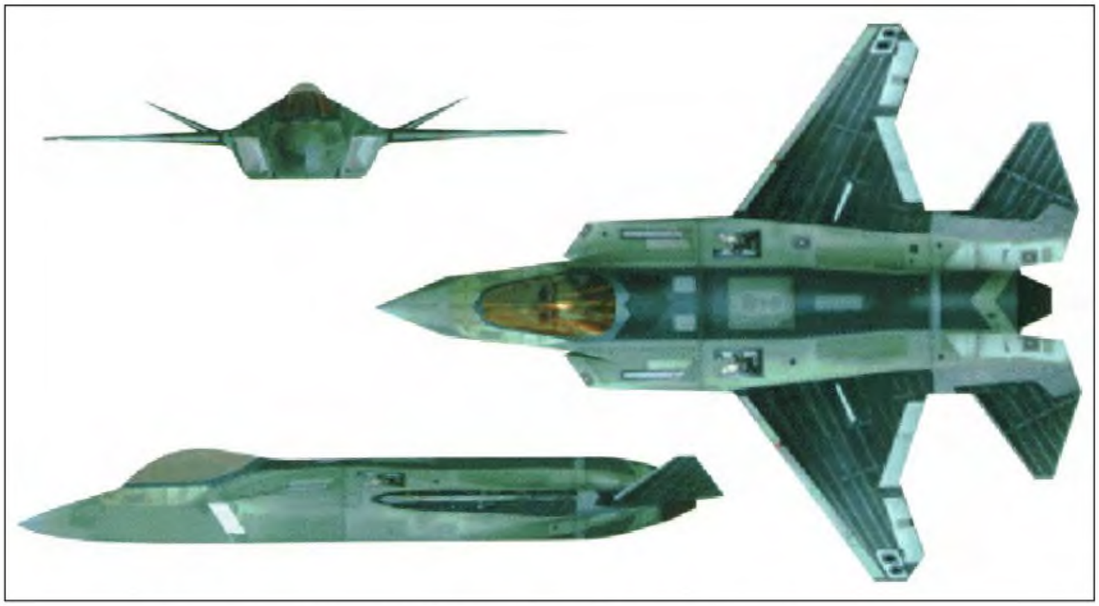

Figure 79: MDA/NGC/BAe JAST 10 Three-View Drawing

The JSF Program Office did not select the MDA/NGC/BAe team to move into the Concept Exploration phase of the program. Northrop Grumman and BAe eventually joined the Lockheed Martin team and McDonnell Douglas ended up merging with Boeing in mid-1997. An overview of the MDA team design evolution, as well as that of the members prior to teaming, is given in Figure 80.

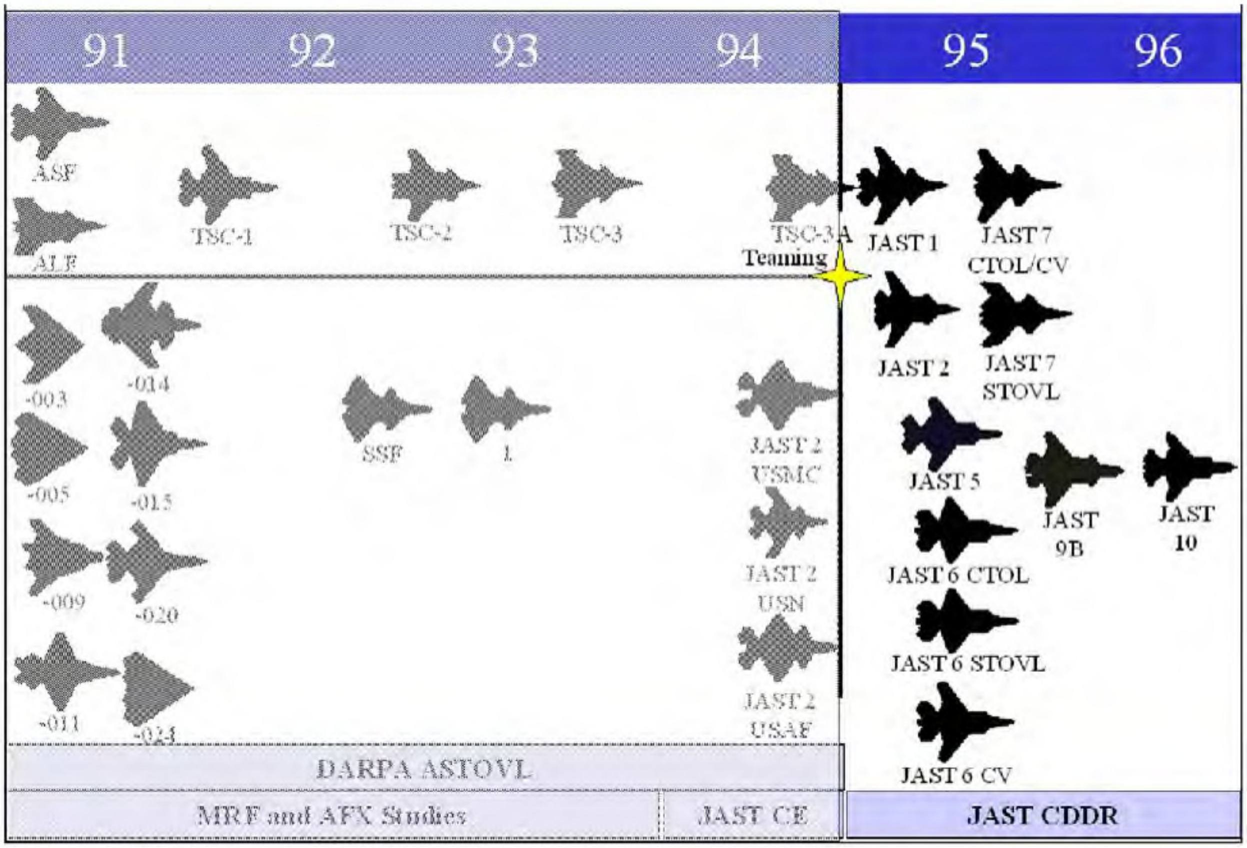

Figure 80. MDA team concept evolution.

6.4 Boeing

6.4.1 Boeing Design Evolution from ASTOVL to Concept Exploration Phase

Boeing's participation in the DARPA ASTOVL studies was funded internally until the company signed an agreement with DARPA in the spring of 1994 for a 50/50 cost sharing plan.[10] Boeing realized early on that the primary design driver for an ASTOVL/CALF/JAST contract would be affordability.[11] Therefore, Boeing set out to find an aircraft concept that would be able to be highly common between the planned variants.

Boeing considered a variety of planforms when the company entered the ASTOVL program and settled on three main planforms (as illustrated in Figure 81), a delta wing, delta with tail and wing/body/tail.

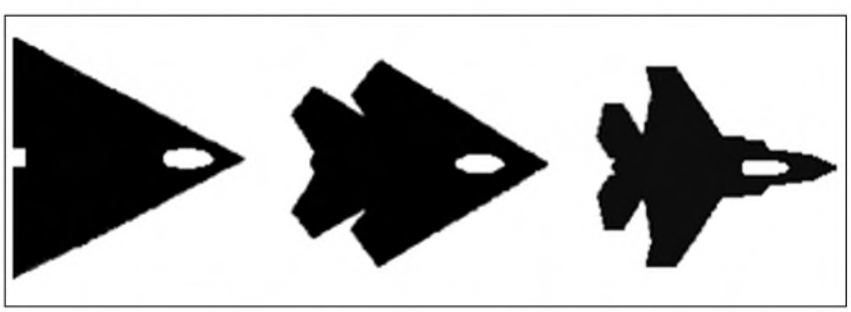

Figure 81: Boeing's Three Main Planforms

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The Boeing ASTOVL concept evolved from a wide range of Boeing tactical aircraft configurations including those from the ATF, MRF and A/F-X studies. After further trade studies, the Boeing ASTOVL concept matured into a modified delta wing with twin fins and a chin inlet located underneath the cockpit.[12] The 44.9 ft long ASTOVL aircraft had a 36 ft span delta wing planform (aspect ratio of 1.12) with wing-tip fins and a two-dimensional vectoring nozzle. The ASTOVL aircraft was designed to be powered by an F119-derivative engine (SE614) and was to be based on the concept of direct lift, which has been proven by the Harrier STOVL aircraft.[13] The ASTOVL aircraft that Boeing was designing was highly modular and had only three major assemblies: forebody/inlet, wing/tails/control surfaces, and the fuselage. The continuous, one-piece wing was 797 ft^2, carried the loads across the top of the fuselage, and was to be capable of containing 18,000 lbs of fuel. The wing had been designed to be constructed of welded thermoplastics so that no fasteners would be required and it was to have comprised 57% of the weight of the aircraft. Boeing planned to use composites throughout the aircraft (greater than 50% of the structure) for weight reduction.[14]

Following more trade studies in 1992, Boeing settled on a blended delta wing body that was dubbed AVX-70 (Figure 82). Attributes of the AVX-70 included a lower signature, a large internal payload/fuel capacity, lightweight structure, low supersonic drag, good high-alpha characteristics and a low aspect ratio offset by low wing loading.

In early 1993, Boeing selected a derivative of the Pratt & Whitney F119 engine as the preferred powerplant for their aircraft. The design was now known as the 988-201. Towards the end of 1993, Boeing added a naval (CV) capability to the ASTOVL 988-201 design, and also created the first JAST specific design, designated the 988-300.

Boeing activities during the CE phase of JAST were primarily focused on the assessment and confirmation of affordability payoffs for a modular, common multi-service strike weapon system. Boeing's efforts consisted of five contract tasks. Under Task 1, Weapon System Baseline and Refinement, Boeing established point-of-departure configurations for the USAF, USMC, and the USN variants. These point-of-departure configurations were updated on a regular basis to incorporate beneficial characteristics identified by trade studies. These studies were planned to lead to a preferred concept by 15 August 1994 and then a freeze configuration by 7 September 1994. Following the configuration freeze, Task 3 (Feasibility/Affordability Confirmation) was initiated to conduct a more detailed assessment of design configurations for the three services and to verify performance and cost estimates. Under Task 4, Boeing developed an electronic mock-up of various configurations, specifically the mid-to-aft fuselage and wing connection to demonstrate the applicability of the evolving technology and identify associated cost benefits.

Figure 82: Boeing AVX-70 Configuration

Finally, under Task 5, Boeing identified risk items and established plans and schedules to demonstrate technologies and identify alternate paths if necessary.[15]

During the CE phase, Boeing conducted eleven trade studies that addressed several configuration issues. Those studies were; level of commonality; engine type and number; crew size; signature; avionics; weapons type and number; high lift system; vehicle subsystems; stability and control arrangements; nozzle designs and missions. Several nozzle designs were considered, a 3-lobe nozzle undergoing testing is shown in Figure 83.

Figure 83: Boeing JAST Gas Ingestion Model Showing 3-Lobe Nozzle

These trade studies led Boeing to updated versions of their point-of-departure configurations. Boeing then made configuration updates based on cost, tri-service utility, and transition potential. Examples of the updates were evident in the -300B/-301B/-302B configurations. They featured a smaller, lighter weight tri-service common wing and a leading edge vortex flap high-lift device for the USN configuration.

For each area, specific trade variations were identified, appropriate CAD models were generated, weights, aero, signature, and propulsion integration assessments were completed, and the configuration was sized for a typical mission. To provide a consistent comparison of how different trade areas affect the lifetime cost of the aircraft, most trade studies used the USN strike mission for aircraft sizing. USAF and USMC design missions were used only when specific trade items were expected to cause service-unique results.[16]

The wing structure was designed to have an outer mold line that would be common for all three of the variants, with a high part number commonality for the interior structural members. The fuselage, which contains the engine/nozzle and weapons bays, would be attached to the underside of the wing. This component would include service unique features, such as one or two engines, engine longitudinal placement, and weapons bay volume. Finally, the forebody/inlet would feature high part number commonality among the services, including cockpit commonality, while providing the flexibility for service unique features, such as bifurcated versus chin inlets.[17]

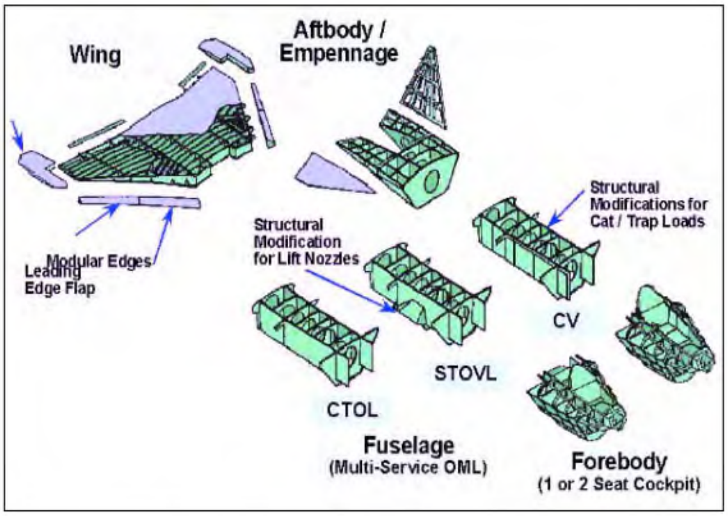

Figure 84: Boeing Modular Concept.

In order to further define the point-of-departure configurations, Boeing began their trade studies with baseline assumptions as to the mission and roles that a JAST aircraft might be tasked to perform. Along with these roles came assumed attributes and capabilities of the JAST aircraft. Boeing first assumed that the JAST aircraft would be a first day fighter; this implied a tri-service design to the greatest extent possible. Boeing further assumed that the basic planform shape needed to be capable of supporting each of the services primary roles and missions, including performing the interdiction strike role, the close air support (CAS) role, and the defense counter air (DCA) role. The platform design needed to be capable of communicating with inter-service air, ground, and sea assets to facilitate a high degree of coordination during combat operations. Boeing designers decided that the aircraft needed to have the capability to utilize information from offboard resources and to share data with support assets both intra- and inter- flight. The basic aircraft design needed to be capable of being modified to handle the basing consideration of each of the services. Boeing's basic JAST design had to be capable of supporting large deck aircraft carrier operations as well as the smaller amphibious carriers. The Boeing team also realized that their aircraft must be able to operate from austere and battle-damaged airfields.[18]

Boeing made these initial assumptions and decisions based upon information from the JAST Program Office Requirements directorate. Boeing also has a variety of experience related to tactical aircraft. Some of these sources included current contracts such as the ARPA ASTOVL and the Air Force F-22 programs, as well as from past contracts on MRF and the A/F-X. The requirements and design guidelines also flowed from the hundreds of MIL standards, specifications and other reference documents provided by the DoD acquisition process. Boeing stated several times during this period that it should be stressed that the initial assumptions and guidelines are just that: initial. Boeing stated that they expected the requirements to change and therefore their design.[19]

While conducting the various trade studies, Boeing concluded that their design needed to be highly survivable in moderate to high threat environments. Signature level requirements dictated the internal carriage of ordnance or LO carriage of external weapons for certain missions. It was accepted that the design had to be highly mission flexible. That implied the ability to carry, deliver and support non-precision, precision, and standoff air-to-ground and air-to-air ordnance. The aircraft would need the capability to carry air-to-ground and air-to-air ordnance in both low observable and "truck mode", where ordnance would be carried on external pylons. The aircraft was also required to have an air-to-air self-protection capability when armed in a strike configuration. The ideal aircraft would have had the ability to vary the mission profile depending on the range and ordnance required as well as the threat environment of the mission.

As discussed above, the CALF and JAST Concept Exploration Phase concepts had vertical fins located at the wingtips, but these were moved inboard and toward the aft end of the blended wing-body for improved balance, lateral/directional stability and control characteristics. The first Boeing CDDR concept (988-301) had a delta-wing with no horizontal tail, and a chin inlet beneath the nose with a translating cowl to vary the airflow capture area (as shown in Figure 85).

Figure 85: Wind Tunnel Model of Translating Cowl

The Boeing LSPM (shown in Figure 86) was tested at a Boeing-built outdoor test facility in Tulalip, Washington, between September and December 1995. The 94% scale model was powered by a P&W YF119 engine.[20] Both Boeing's and Lockheed's LSPMs were tested on rigs that permitted a variety of information to be gathered with the model positioned at altitudes ranging from wheels-on-ground up to approximately 50 feet above ground. Flow velocities, temperatures and pressures in the vicinity of the model were measured, providing a means to validate each contractor's predictions that were based on computational fluid dynamics (CFD) analysis and sub-scale model tests.

Figure 86: Boeing LSPM

6.4.2 Boeing Design Evolution to Concept Definition Phase

The Boeing CDDR concept was a delta-wing with no horizontal tail, and a single engine inlet beneath the nose with a translating "chin" to vary the airflow capture area. The CALF and JAST Concept Exploration Phase concept had vertical fins located at the wingtips, but these were moved inboard and toward the aft end of the blended wing-body early in 1995 for improved balance and improved lateral/directional stability and control characteristics.

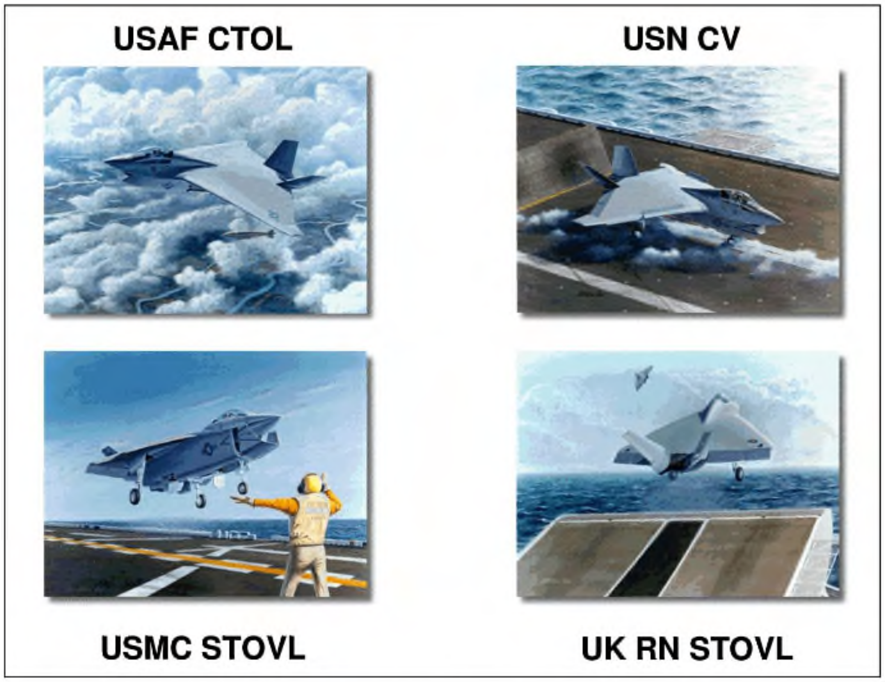

Figure 87: Boeing JSF CDDR PWSC Configuration

For the Marine Corps and the UK Royal Navy JSF variant, Boeing selected a direct-lift STOVL configuration because of inherent lightweight and proven application on the AV-8B Harrier. This simple concept has the least impact on the basic airframe structure, better lends itself to a common modular approach for all four services, and is the lowest cost solution. The Boeing JSF concept not only meets the UK Harrier replacement needs, but may meet the requirements for the UK Future Offensive Aircraft (FOA) as well. Other allies have voiced interest in the JSF Program and Boeing believes there will be a substantial international market for the low-cost, high-performance strike aircraft.

The STOVL variant utilized a direct lift scheme, derived by vectoring main engine thrust downward. The cruise nozzle was blocked off for hover, and the bulk of the engine exhaust was directed downward through two lift nozzles on the sides of the lower fuselage. A portion of the engine fan flow exited from a forward "jet screen" nozzle to prevent hot gas re-ingestion into the inlet.

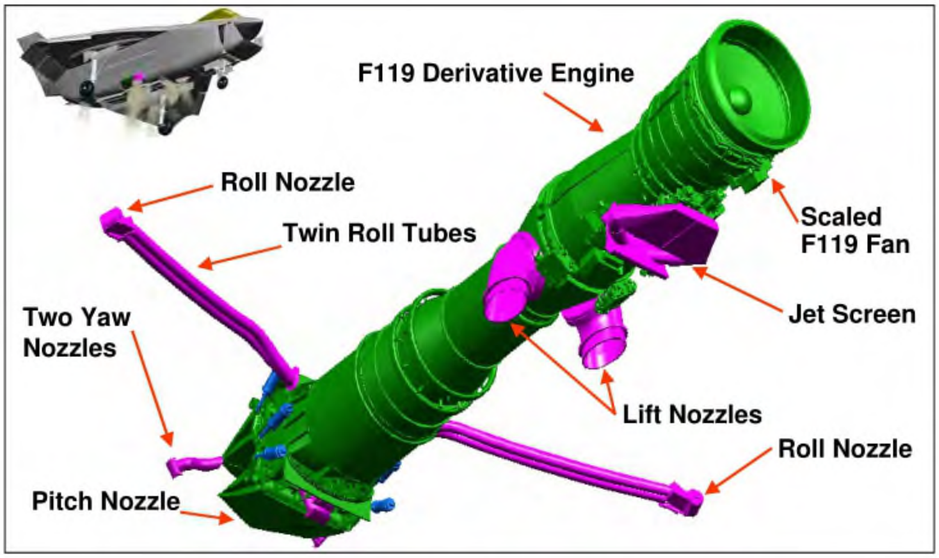

Figure 88: Boeing CDDR Propulsion System

Additional PWSC features included:[21]

- Pratt & Whitney (P&W) SE614 derivative of the F119 engine
- Pitch-axis thrust vectoring in wing-borne flight on all variants
- Single-piece, common, thermoplastic primary wing structure on all variants, with customized fuselage mounted to the wing
- Weapons bays accommodated two 1000 lb bombs (STOVL variant) or two 2000 lb bombs (CTOL and CV variants), plus air defense missiles internally

By the summer of 1996, Boeing had completed more than 11,800 hours of highly successful JSF-related tests. Some of the major areas of the Boeing test program included: low-speed and high-speed aerodynamics and propulsion testing; high angle of attack testing; STOVL ground effects testing; handling quality dome simulations; virtual avionics prototypes dome simulations; weapons integration and separation testing.

One of the major successful Boeing JSF design validations was completed in April 1996 in another Seattle-area Boeing test facility, the Indoor Radar Range, where Boeing engineers used a full-scale model of the company's JSF in RCS tests (Figure 89). The RCS tests were so successful that Boeing needed only a few hours to validate the design instead of the weeks originally scheduled to match results with detailed pre-test predictions. The radar range tests strongly validated not only Boeing's unique design but its basic analysis and test methodology as well.

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Figure 89: Boeing RCS Model.

An overview of the Boeing concept design evolution is given in Figure 90.

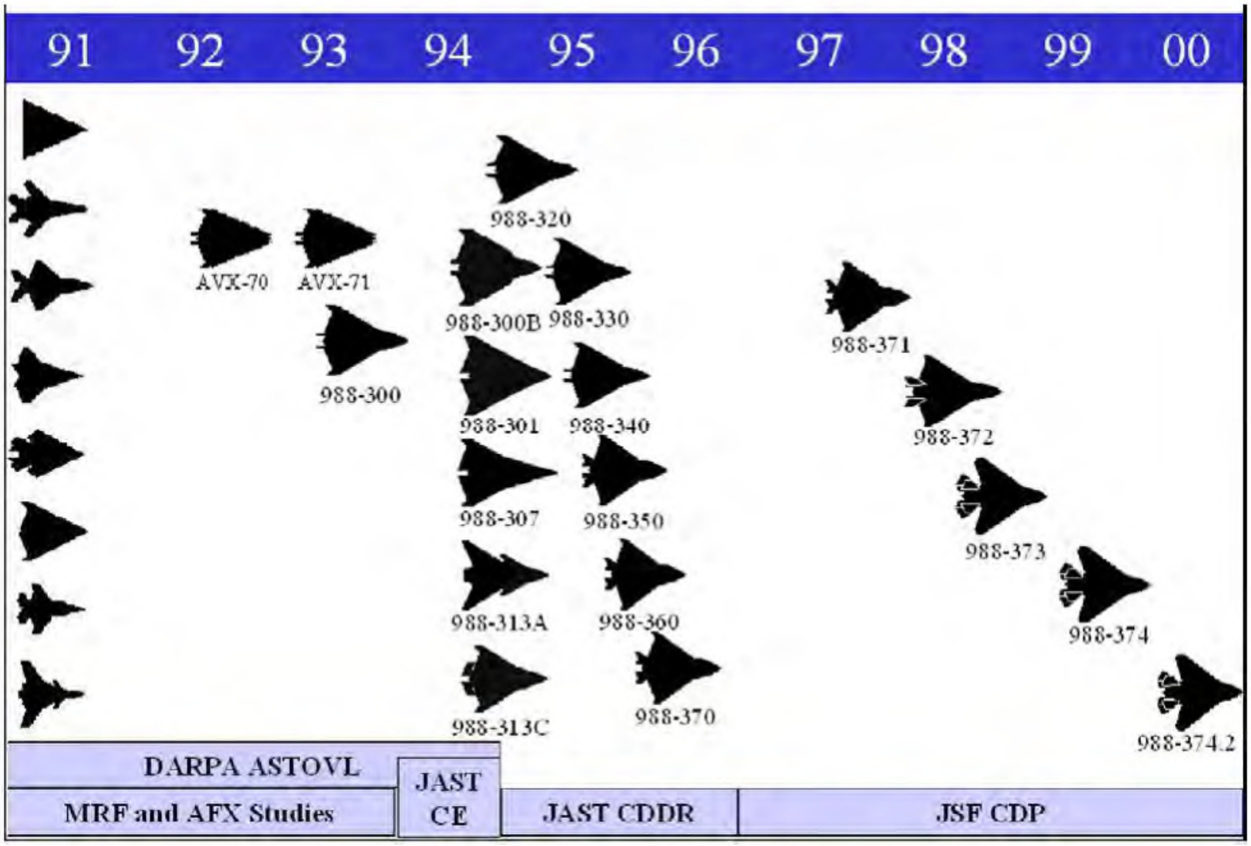

Figure 90. Boeing Concept Evolution.

6.4.3 Boeing CDP Design Refinement

On 15 December 1996, just a month after the JSF CDP source selection decision, Boeing and McDonnell Douglas announced their intents to merge. McDonnell Douglas brought experience with a great number of strike and fighter aircraft – including the USAF F-15, the carrier-based A-4, F-4, and F/A-18, and the STOVL AV-8 – to Boeing's JSF team. On 1 July 1997, the U.S. Federal Trade Commission (FTC) unconditionally approved the merger, which formally closed on 4 August.

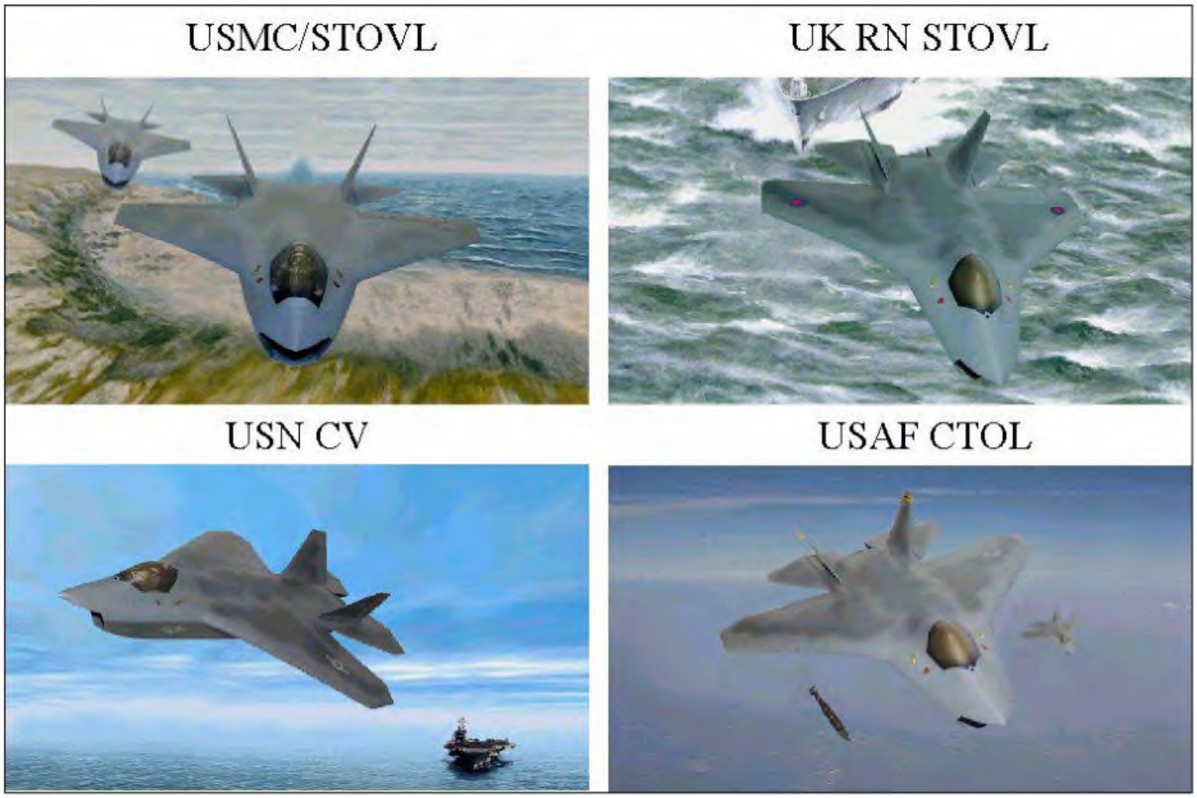

Figure 91: Boeing Preferred Weapon System Concept

The Boeing JSF design exploits experience in modern composite materials and manufacturing processes gained in the commercial 777 and next generation 737 jetliners, the B-2 bomber, the Condor UAV, the F/A-18E/F naval strike fighter, and the F-22 air dominance fighter, as well as through internal research and development (IR&D) conducted at the Boeing Phantom Works in St. Louis, Missouri.[*] The unique expertise accrued in these key technologies significantly contributes to the light weight and low cost of the Boeing JSF concept. Recognizing the need to validate its JSF design concept concurrent with engineering and program milestones, Boeing has conducted a series of simulations and tests, totaling over 18,000 hours by the end of 1999. A list of subscale tests at various facilities, including company facilities, research agencies, subcontractors, and NASA Langley Research Center (LaRC), is given in Table 25.

Table 25: Boeing JAST/JSF Tests

Test Facility	Test	Scale
Microcraft Low Speed Wind Tunnel	Airframe Aerodynamics	10%
CALSPAN Transonic Wind Tunnel	Aerodynamic Loads	10%
AEDC 4-Foot Transonic Tunnel	Weapons Separation / Acoustics	5%
Rolls-Royce	Hot Gas Ingestion	6.5%
University of Washington Water Tunnel	Aerodynamics / High Angle of Attack	3%
Boeing Propulsion Wind Tunnel	Low Speed Inlet / Re-ingestion / FOD	13%
Boeing Tulalip	Large Scale Powered Model	94%
AEDC	High Speed Inlet Testing	13%
Boeing Nozzle Test Facility	Lift Module / Spool Duct Test	17%

[*] On 16 September 1999, Boeing announced the re-alignment of the Phantom Works from St. Louis to Seattle.

NASA LaRC	Suckdown	10%
Boeing Nozzle Test Facility	Suckdown	10%
NASA LaRC 20-Foot Vertical Spin Tunnel Rotary Balance	Spin Testing	10%
Boeing Transonic Wind Tunnel	Airframe Aerodynamics	7%
Boeing Supersonic Wind Tunnel	Airframe Aerodynamics	3%
NASA LaRC 14 by 22-Foot Subsonic Wind Tunnel	Airframe Aerodynamics	15%
NASA LaRC 16-Foot Transonic Wind Tunnel	Transonic / Supersonic Inlet	12%
Defence Research Agency (DRA)	Transonic / Supersonic Inlet	12%
Applied Research Associates (ARA)	Jet Effects	9%

Boeing held their Lift Systems PDR for Rolls-Royce (RR) components on 25-26 February 1997, covering the lift module, spool duct, jet screen and attitude control system. This was followed up by a CDR on 23-26 September. Since Boeing subcontracted directly with RR for these lift system components (and not through P&W), the reviews were held in the UK (P&W activities are covered in Section 5.4.1).

By August 1997, Boeing had completed several major subscale tests of their STOVL propulsion system. The first test, conducted at the Boeing Nozzle Test facility in Seattle, evaluated the RR lift components. The 17% scale model was used to assess the performance and operability of the lift module and spool duct during conventional flight, STOVL operations, and transition from one flight mode to the other. The full range of JSF nozzle pressure ratios, mass flows and lift module positions also were evaluated. At the Arnold Engineering Development Center (AEDC) in Tullahoma, Tennessee, Boeing conducted a three-week-long evaluation of the performance of the high-speed inlet/forebody compression system. The tests employed a 13% scale model and encompassed the full range of JSF flight speeds and attitudes. Approximately 211 hours of testing covered subsonic, transonic and supersonic airspeeds, at various attitudes.

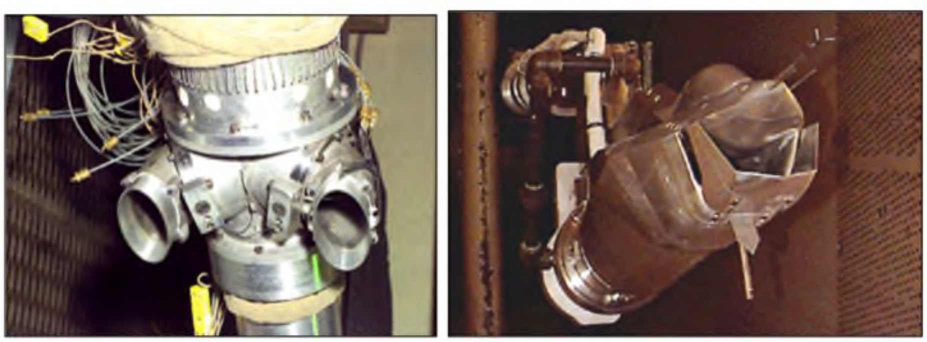

Figure 92: Boeing Lift Module (left) and Inlet/Forebody (right) Test Models

Boeing completed four full mission simulations (FMS): October 1997, August 1998, May 1999, and June 2000. By using advanced real-time technology, the FMS is capable of demonstrating the characteristics of the Boeing JSF in both integrated and operational mission environments. Located at the Developmental Center near Boeing Field in Seattle, the FMS is a significant step toward satisfying three critical proposal technology requirements: 1) onboard/offboard data fusion, 2) single seat cockpit and pilot vehicle interface, and 3) warfighting capability. Using a piloted-dome environment, all three technologies are demonstrated within real-time mission scenarios provided by the JPO. Several of the demonstrated weapon system characteristics that will be on the operational aircraft include mission management functions, sensor modeling and tasking, data communication, radar simulation, functionality and display formats, and operations within the JSF System-of-Systems. By the time of the fourth FMS in Boeing had significantly matured the functionality of the simulation. This final FMS, completed on 9 June 2000,

demonstrated the Boeing PWSC capabilities to pilots from the U.S. Air Force, Navy, Marine Corps, and the U.K. Royal Navy, flying approximately 100 simulated air-to-air and air-to ground missions over a seven-day period.[22]

As avionics capabilities mature, they are integrated and tested in a series of demonstrations that led to a flight test program using a highly modified Boeing 737-200 Avionics Flying Laboratory (AFL), as seen in Figure 93. In a less-than-one-year design and modification program, Boeing Military Programs, Wichita Division, fitted a 48-inch nose and radome assembly to the forward pressure bulkhead of the AFL. The elongated nose contains avionics and instrumentation to aid in the development of the Boeing JSF aircraft. The AFL also was fitted with several antennas, a heat exchanger and provisions for a supplemental power system. The AFL flew with its structural modifications for the first time on 9 April 1999 from Wichita, Kansas.

On 9 December 1999, Boeing began seven months of integrated avionics testing with the first test flight of the AFL. Boeing expects that the AFL will significantly reduce technical risk in JSF avionics development by allowing engineers to evaluate and troubleshoot the avionics systems before they are installed on the JSF. The reduced technical risk translates into significantly reduced avionics costs later in the program. During the first flight, engineers tested the core avionics processor, various sensors and mission software. A representative JSF cockpit has been installed in the airplane's cabin. The AFL carries a crew of avionics engineers, who monitor test data, fix problems and direct testing to take advantage of emerging results. With near instantaneous fusion of data from on-board and off-board systems including other aircraft and the battlefield, the Boeing PWSC JSF avionics system frees the pilot from actively managing data flow in the cockpit. This allows the pilot to be a more effective tactician and better focused on the mission at hand.

Figure 93: Boeing 737 Avionics Flying Laboratory After Structural Modifications

Key components to be tested with the AFL include radio-frequency and electro-optical sensors and a prototype core processor. The processor, which runs the mission-system software, uses an open architecture that enables reuse and easy portability. In more than 200 hours of F-22 avionics testing experience aboard a Boeing 757 flying test bed, Boeing demonstrated how a test-bed approach can reduce avionics development costs, risk and future flight-test hours. The lab's superior range allows more thorough testing; it carries more instrumentation than a fighter can and doubles as a laboratory on the ground for tests that don't require flight conditions. Unlike a static ground-based lab, the AFL will demonstrate JSF capabilities in a dynamic, airborne setting against a wide variety of real targets embedded in their environments. This testing supports the current concept development phase of the JSF program and runs in parallel with flight testing of the concept demonstrators. By May 2000, Boeing had demonstrated multi-sensor fusion of its JSF avionics on the AFL.[23]

In June 2000, Boeing demonstrated the integrated weapon system capabilities of its JSF design during a live-fire exercise conducted at White Sands Missile Range, New Mexico. The AFL used its JSF mission systems suite to gather targeting data from off-board systems, fuse it with data gathered from on-board

systems and then provide refined targeting information to an F-15, allowing it to successfully attack a ground target with a GPS-guided JDAM. Boeing also demonstrated the ability to link its JSF full-mission simulator in St. Louis with U.S. Air Force Air Combat Command F-15 simulators at Eglin Air Force Base, Florida, in order to conduct real-time cooperative training missions. The scenarios, with JSF and F-15 pilots flying together in the same threat environment, demonstrated how aircrews at different locations, with different types of aircraft, can practice JSF-representative missions together via a government-standard high-level architecture data network. [24]

On 29 July 1998, Mauser-Werke Oberndorf, Primex Technologies, Inc. and Boeing signed an agreement to jointly produce a 27-mm cannon for JSF. The 27-mm cannon is a gas-operated automatic revolver gun based on the Mauser BK 27 cannon in use by NATO and Allied forces. Variants of the 27-mm cannon have been selected for the multi-national Eurofighter Typhoon and are in use on the SAAB-BAE Gripen.

On 30 September 1998, Boeing announced the major suppliers comprising the Boeing JSF Industry Team. The team is comprised of:

- Flight Refueling, Ltd., of Dorset, England (fuel system)
- Marconi Electronic Systems of Stanmore, England (vehicle management system and cockpit displays)
- Messier-Dowty, Ltd., of Gloucester, England (main and nose landing gear system)
- Pratt & Whitney of West Palm Beach, Florida (JSF119 engine and exhaust nozzle)
- Raytheon Systems Company of Arlington, Virginia (select mission systems)
- Rolls-Royce, plc., of Bristol, England (vertical lift propulsion system, attitude control system).

The X-32 Final Design Review (FDR) was held in Seattle on 13-15 October 1998, in conjunction with a CDP PMR. Successful completion of the FDR gave Boeing the confidence to forge ahead with the manufacturing and assembly of their X-32 design. The FDR was broadcast to The Boeing Company's Rosslyn, Virginia facility via video teleconference (VTC) for approximately 30 government and industry members. Maj Gen Kenne was extremely pleased with this process and challenged other teams to similarly use VTCs to minimize travel to large reviews.

In addition to using VTCs for program reviews, Boeing is making paperless contract reporting a standard business practice using its Program Visibility System (PVS). For example, Boeing recently submitted a contract modification using PVS. Boeing and the JSF Program Office are using the Internet to bring the benefits of electronic commerce – with its real-time data transfers and instantaneous communication – to defense contracting. Boeing has been delivering electronic contract progress reports to the JSFPO since February; other types of Boeing JSF data have been available electronically since December 1996. Instead of taking paper delivery, government officials are given secure accounts on PVS, which allow them to display the contract reports on their computers and to print them if they choose. PVS's broad network connections give employees access to a single source of data without regard to their geographic location. The system provides near-real-time updates, more complete data and clear accountability so that Boeing and its customer can identify and resolve issues faster.

During the spring of 1998, the Boeing JSF team began to look at alternate concepts for their Primary Weapons System Concept (PWSC). As part of their trade studies to reach a low cost PWSC design, Boeing began considering a series of changes that was finalized by the end of 1998 as their PWSC configuration 988-373 (officially announced on 4 February 1999). The -373 design evolution incorporates a horizontal tail into the design of the aircraft, thus dispensing of the delta wing shape of the X-32A/B and moving to a more traditional wing-body-tail design. Boeing believes that the lower weight design of the -373A has improved control and maneuverability, particularly for the STOVL and CV versions. It has also added versatility in projected weapon and fuel payloads, and reduced frontal RCS according to RCS model tests (see Figure 94).

Figure 94: Boeing Full-Scale RCS Test Article

In April 2000, Boeing began validated the radar, antenna and stealth performance of its concept for the operational JSF using a high-fidelity, full-scale aircraft model. The Supportable Electromagnetics Test Aircraft (SETA) model was evaluated at the Boeing Compact Radar Cross-Section Test Range in Seattle. Key features of the model included the antenna apertures for communication/navigation/identification and electronic warfare propulsion components, radar and radome, doors and access panels, moveable control surfaces, a functional weapons bay, specialized lighting and coatings, and a canopy; these components were flight-quality parts built in production shops.[25]

Figure 95. Boeing SETA RCS Test Model. [26]

Boeing successfully completed their third PMR on 24 February 1999. Also that month, Boeing announced a projected $35 million cost overrun. The overrun was later reduced by the replan (discussed in Section 5.1.5) that trimmed planned, but not required, work from the X-32 program. All statement of objectives requirements will still be met.

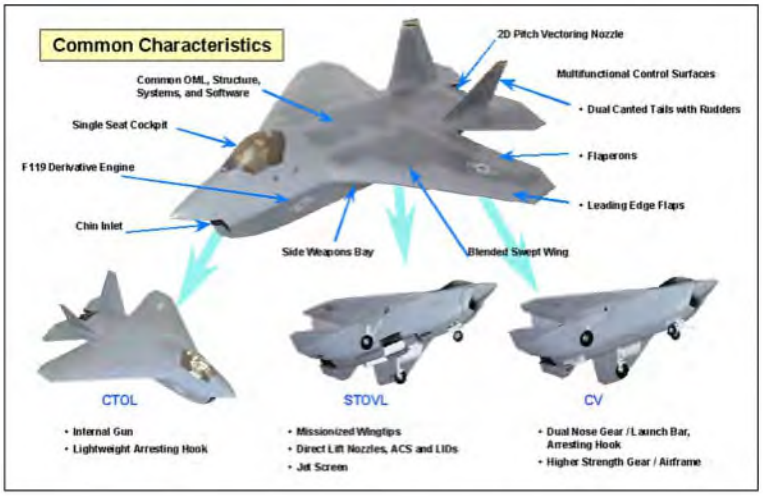

Figure 96: Boeing PWSC Service-Unique Systems

In the Boeing –373 PWSC design, there are three major elements that have obviously been changed. First, the 36 ft wide wing is no longer a diamond delta, it has been changed to a more conventional swept wing. Second, a horizontal tail has been added to the aircraft, each side of which is capable of moving as a single piece. By adding the tail, the fuselage has been lengthened by two feet to 47 ft. Finally, the shape of the chin engine inlet has changed from a forward sweep to a rearward sweep, and the canopy is shorter and wider. Only minor changes to the propulsion system (primarily in the Attitude Control System (ACS)) were made, as shown in Figure 97.

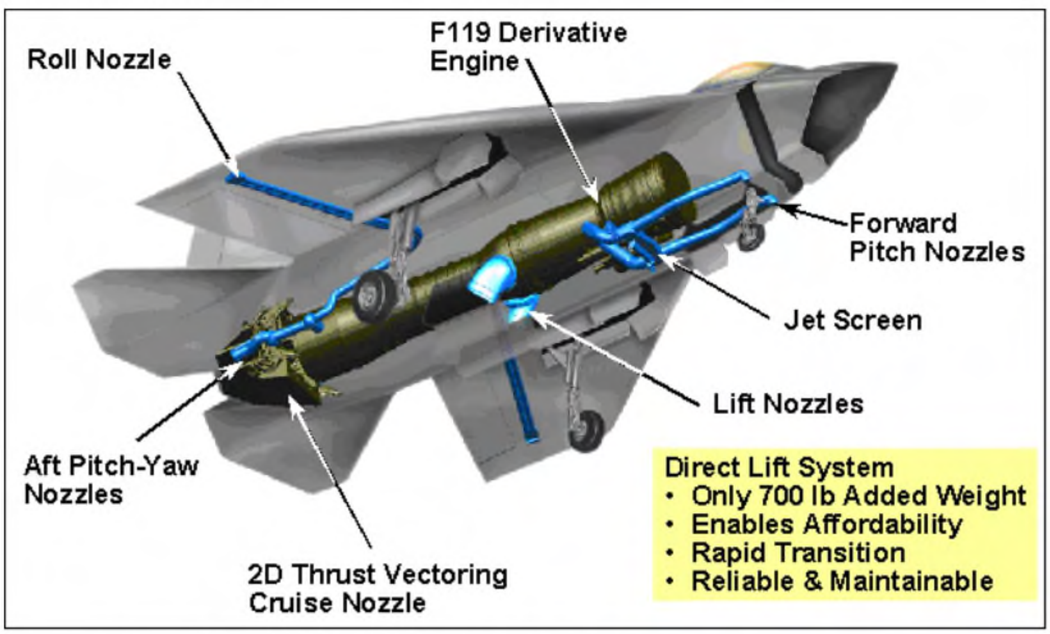

Figure 97: Boeing PWSC STOVL Propulsion System (-374 Shown)

During Boeing's fourth PMR on 26-28 October 1999, Boeing reviewed its -374 configuration to the JSFPO (see Figure 98). As with the October 1998 FDR/PMR, the PMR was broadcast to The Boeing Company's Rosslyn facility via VTC for approximately 30 government and industry members. The PMR was successfully concluded on 28 October and the -374 configuration was made public on 1 November. There are relatively few changes from the -373 to the -374: the trailing edge of the wing still has a flaperon,

but instead of being a lift and pitch device, it is now used for lift and maneuvering, as the tail is now the primary pitch control device. The shape of the vertical stabilizers has changed, but retain the same angle, area and control power. Small air inlets were also added next to the cockpit canopy to provide cooling air for environmental controls; originally this was provided by inlets within the engine inlet, but tests showed they would not provide sufficient cooling air from this location.

Figure 98: Boeing –374 PWSC Concept (CTOL Shown)

Figure 99: X-32A and PWSC Artist's Rendering

It should be noted that the Boeing X-32 CDA set to fly during CDP will be based on the -371 delta wing design and will not have a horizontal tail. Obviously, the PWSC changes discussed here will only be implemented if Boeing is selected to enter the EMD phase of the program. Boeing will, however, still fulfill the three objectives of CDP: commonality (building the two CDAs at the same time on the same tooling), STOVL hover and transition (using a relatively unchanged propulsion system) and carrier approach

(validating design models and control logic). Sub-scale tests have indicated that performance in carrier approach and landing, as well as forward and vertical flight, is improved by the new configuration.

6.4.4 Boeing CDA Assembly

Boeing conducted their second PMR on 2 April 1998, by presenting briefings on design and affordability data for both current and future program phases to the JPO, and representatives from the governments of the UK, Canada, Denmark, Norway, and The Netherlands. Additional briefings and discussion focused on cost reduction, weight management, inlet testing, mission systems, upcoming mission simulations and cockpit configuration.

Boeing successfully passed its X-32 Initial Design Review (IDR) in early September 1997, paving the way for the fabrication and assembly of the two test aircraft. Fabrication of the first major CDA component—an upper center fuselage frame—began on 19 November 1997 in Seattle, Washington. The frame is an integral part of the JSF mid-fuselage forward frame assemblies.

Figure 100: Fiber Placement on an X-32 Inlet Duct

Boeing announced in February 1998 that the final assembly and first flight of its two CDA would take place in Palmdale, California, with subsequent landings at Edwards AFB. Boeing's JSF program will use its existing facilities in Palmdale to provide the infrastructure for final assembly engineering support, ground testing and preparation for pre-flight checkout and first flight operations. The wings and fuselage were being constructed in Seattle, Washington, and the forebody in St. Louis, Missouri. Overall program responsibility has remained in Seattle.

By mid-April 1998 Boeing had completed the detailed design and initiated fabrication of major sections of the forward fuselage for their two CDA. Extensive use of computer 3-D modeling and simulation technologies has replaced the prior method of creating time-consuming drawings and expensive test hardware. Boeing passed another major development milestone on 23 July 1998 by successfully completing the first in a series of avionics demonstrations.

At the Boeing Phantom Works in St. Louis, Missouri, structural assembly began on the X-32A (CTOL/CV) CDA on 8 July 1998. When the forward fuselage was completed, it was shipped to the

Palmdale facility for mating to the mid-fuselage, which began assembly during August 1998. The first composite wing skin (shown in Figure 101), was delivered to Boeing's final assembly plant in Palmdale, California on 4 November 1998. The skin weighs 742 pounds and is nearly 29 ft across. The single-unit wing reduces the overall weight of the aircraft by eliminating heavy side-of-body wing attachments, and has increased strength, fuel volume and sealing advantages over wings with multiple pieces. Assembly on the X-32B (STOVL) forebody began two months ahead of schedule on 23 September 1998.

Figure 101: X-32A Single-Unit Wing Skin

Another milestone was accomplished on 15 December 1998 with the installation of major skins in the X-32A forebody. On 22 December 1998, a pressure test was successfully conducted, paving the way to final assembly of the cockpit structure. The last composite mold tool was also completed during 1998. This tool will be used to fabricate the composite inlet cowl.

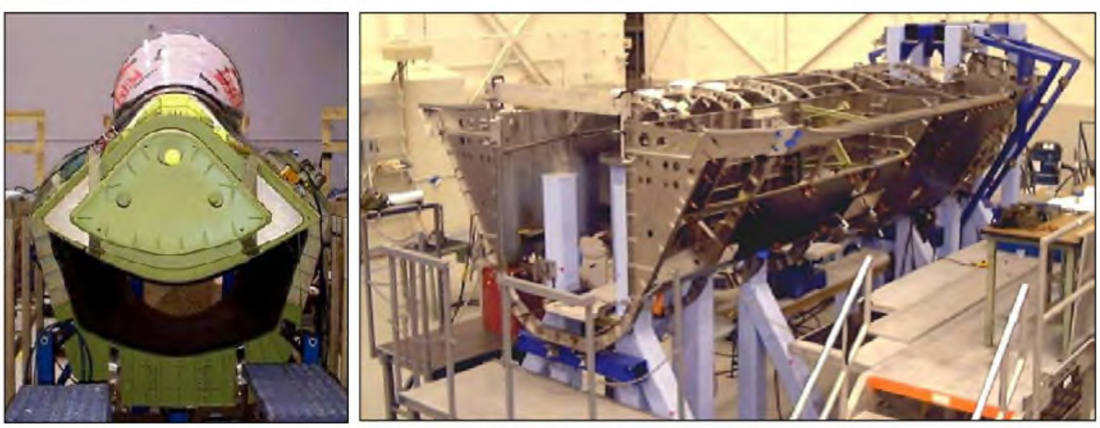

Figure 102: X-32 Frontal View and Fuselage Assembly

Boeing successfully completed the first test phase of the vehicle management system (VMS) for its X-32 demonstrator aircraft during early July 1999. The VMS operates the flight controls, including the actuators and hydraulics, the environmental control system and other subsystems. Boeing is using a full-

scale actuator test rig that simulates the aircraft's hydraulic and actuation systems. Both engine-driven pumps and auxiliary power unit-driven pumps are used to power the hydraulic systems. Testing of actuation performance, onboard diagnostics, pilot displays, avionics and utility systems, and sensor monitoring were well under way at the end of 1999.

The actuator test rig enables engineers to verify the operation of the flight-control surface actuators with the integrated flight- and propulsion-control hardware and the operational flight software. The rig is an exact copy of the X-32 actuation system, ensuring a match between the system performance observed in the laboratory and what will be measured on the aircraft during ground and flight testing. Integration of the electrical and hydraulic subsystems, actuation and cockpit, including displays and controls, are all complete. Test results can be correlated directly to the X-32 without adjustments for scaling or missing elements, making the test process more efficient. Potential interactions between hydraulics, actuators and software are identified and resolved early. To help keep JSF Program costs down, Boeing is re-using laboratory components, including instrumentation, hydraulic drive motors and actuator load systems used in similar testing for the 777 and the F/A-18 Hornet. The actuator test rig is one piece of the complex and highly sophisticated Vehicle Integration Laboratory Boeing has installed in Seattle. JSF engineers are using the lab to integrate and refine the vehicle management system and to demonstrate the system's ability to meet all X-32 safety and functionality requirements.

Throughout 1999, the X-32A and X-32B rapidly took shape on the assembly floor in Palmdale. The X-32A final assembly began on 2 April with the mating of the fuselage. The wing was mated to the fuselage on 13 June. A small team of mechanics positioned and mated all of the attach points between the wing and the fuselage within six hours. Boeing stated that the two sections practically snapped together, further validating Boeing "lean" concepts. Laser-tracker devices on the factory floor used 3-D design data to locate the parts for nearly tool-less wing assembly. Self-locating features designed in the X-32 parts allowed for the quick and easy assembly in simple, inexpensive holding fixtures.

Three-dimensional solid modeling and assembly simulation, laser-guided part positioning and minimal tooling are some of the advanced approaches that Boeing has used throughout the JSF program. Due to these and other "lean" concepts, overall X-32 fabrication and assembly costs remain at 30 to 40% below projections that were already low compared to previous aircraft development programs. Also, largely due to digital design processes, no unplanned shimming has been required in the assembly of the X-32A.

Figure 103: Boeing X-32A Wingmate

The electrical system was powered up for the first time during late July 1999. The cockpit's interior lighting, multifunction displays, heaters and several display panels were the first systems powered by an external source. Each system tested was fully operational. Static testing began on the X-32A airframe in

mid-August (just four days late to the plan that was established in 1996); the stick and multi-function displays were installed and all of the flight control surfaces were exercised during late August.

Figure 104: X-32A Being Transported to Fuel Calibration Test

Boeing and Martin-Baker completed the testing of the X-32 ejection seat at 260 kt in September 1999 (Figure 105). The ejection seats were delivered for installation into the aircraft at Palmdale during the latter part of October.

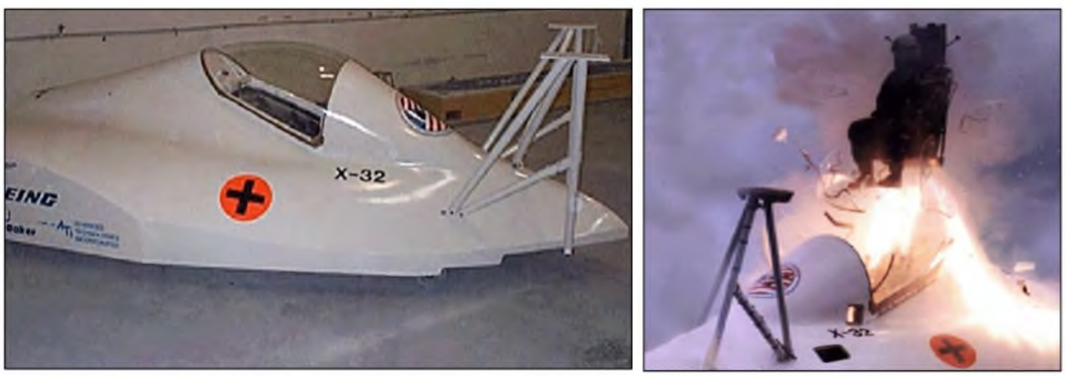

Figure 105: Boeing/Martin-Baker X-32 Sled Test

In late September 1999, the wing was stressed to 100% for the first time. The structural proof load testing was successfully completed on 9 October, the landing gear was installed later that month and the air-to-air refueling probe was successfully deployed for the first time in early November. The X-32A fuel system was also tested during late November. The tests validated the ability of the fuel system to refuel and defuel the aircraft, to transfer fuel between tanks for center-of-gravity and thermal management, and to deliver fuel to the engine at all power settings. During the test, engineers calibrated the tanks, including the gauging system. Many of the tests were performed under the control of the onboard automatic vehicle management system.

Due to the advances in computer-aided design and manufacturing, the X-32 aircraft came together very smoothly. This was especially visible when Boeing installed the SE614 engine in the X-32A for the first time in less than three hours. The X-32B forebody arrived in Palmdale ahead of schedule on 29 June. The assembly of the wing for the X-32B took one-third less time than its predecessor and the wing mate occurred on 20 September. The cockpit was successfully powered up during the first week of October; by the end of October, the X-32B electrical systems were being tested, and the main landing gear was installed during mid-November.

Figure 106: X-32B Nearing Completion

On 15 December, at a ceremony to unveil the X-32A to the public, Boeing surprised the audience by presenting both the X-32A and the X-32B in Palmdale, California. The X-32B did not have an engine installed, but its presence at the ceremony showed that its production was several months ahead of the schedule.

Figure 107: X-32A and X-32B at the Transition to Flight Test Ceremony

Following the Transition to First Flight Ceremony, Boeing completed their work on the aircraft and prepared them for their first flights. On 11 April 2000, Boeing technicians installed the engine in the X-32A. The engine, F119-614, designated the YF004, the engine had successfully completed 45 hours of acceptance testing at Pratt & Whitney's facility in West Palm Beach, Fla.[27] Then on 24 April, the engine ran at idle power to verify system integrity, then at all power settings, from minimum to maximum afterburner. The engine was powered up eight times over a six-day period. All propulsion-system

components operated as designed and experienced no anomalies. Emergency system tests and emergency shutdowns also were performed, revealing no issues.[28]

Figure 108: Boeing employees prepare to install the exhaust system for the YF004 engine.

During manufacturing and assembly, sophisticated electronic measurement tools helped Boeing reduce tooling costs for its JSF X-32 concept demonstrators by 72% over the F-22. Boeing also made significant advances during assembly of its JSF X-32 CDAs that demonstrate the company's "design anywhere, build anywhere" philosophy. The results were about 80% fewer defects in the X-32 than in the equivalent build of the YF-22. [29]

It should also be mentioned in early February 2000, the Seattle Society of Professional Engineering Employees in Aerospace (SPEEA) Union went on strike against Boeing. Despite management efforts, the final preparations for flight testing were impacted. Boeing engineers and technicians returned to work on 20 March 2000 after a 40 day walkout.[30]

6.4.5 Boeing Flight Operations

Boeing completed the X-32A CTOL/CV First Flight Readiness Review (FFRR) on 26 April 2000, clearing the way for initial low- and medium-speed taxi tests on 23 May 2000. The taxi tests were performed in order to verify the function and integration of aircraft systems, including steering, braking, engine controls and flight-control surfaces while the aircraft is in motion. Test engineers remained in constant contact with the pilot while observing the aircraft's instrumentation from their control room.[31] The high-speed taxi test, which cleared the path to first flight was completed on 15 September.[32]

Boeing test pilot Fred Knox controlled the X-32A as it left the runway at Palmdale at 10:00 am on 18 September 2000. During the flight, Boeing JSF Chief Test Pilot Fred Knox put the X-32A through some initial airworthiness tests, including flying qualities and sub-systems checkout.[33] The first flight represented the X-32A's entry into a five-month flight-test program at Edwards Air Force Base with approximately 50 test flights totaling about 100 hours to validate the X-32's flying qualities and performance for conventional and aircraft carrier operations.

Figure 109: The X-32A during its maiden flight, accompanied by an F/A-18 of NAS Patuxent River.

Following its first flight, the X-32A underwent routine maintenance until its next flight, which was delayed until 23 September due to high winds that exceeded the limits as defined by the test flight guidelines. Knox then took the X-32A to an altitude of 10,000 feet and attained an air speed of more than 200 miles per hour. During the flight, which lasted 50 minutes, Knox conducted a series of maneuvers and tests to establish the X-32A's basic airworthiness before subjecting it to more strenuous maneuvers on later flights.[34]

On 15 November 2000, the X-32A began field carrier landing practice (FCLP) tests to demonstrate flying and handling qualities during low-speed aircraft carrier approach. U.S. Navy Cmdr. [redacted] the U.S. government's lead test pilot for the Boeing JSF program, and Boeing lead test pilot [redacted] demonstrated simulated carrier landings using a Fresnel lens on the ground to provide pilot cues during their approaches to a simulated carrier deck outlined on a runway at Edwards Air Force Base.[35] The tests were successfully concluded on 2 December.

Figure 110: The X-32A approaches the runway at Edwards Air Force Base during FCLP testing.

Boeing CV accomplishments include 97 approaches and 74 actual touchdowns, as well as numerous "wave-offs," throttle transients and integrated test blocks including roll response and speed stability during the FCLP tests.[36] Flying as many as five flights a day the week of 18 December, the X-32A successfully completed low-speed approach CV tests, marking completion of 100% of the government-defined CV test objectives. [37]

On 19 December, Cmdr. Yates successfully maneuvered the X-32A, flying at 20,000 feet and 235 knots, into a refueling drogue from a KC-10 tanker. It was the first time that the X-32A had successfully attempted and completed an aerial refueling.[38]

Figure 111: First in-flight refueling of the X-32A.

On 21 December, Lt. Col. Edward Cabrera, U.S. Air Force lead test pilot assigned to the Boeing X-32A test program, took the X-32A to 30,000 feet and achieved supersonic flight by exceeding Mach 1.0 at 12:30 p.m. EST. The X-32A completed its flight-test program on 3 February 2001, returning to the company's facility in Palmdale, on its 66th flight. Since its first flight on 18 September 2000, the X-32A completed 50.4 flight hours with six different Boeing and government pilots at the controls.

While the X-32A was conducting its taxi and flight test program, Boeing technicians at Air Force Plant 42 were preparing the X-32B for its first flight. In July, Boeing installed the propulsion system in the STOVL X-32B in less than four hours. By the end of July, P&W had completed a series of tests of its STOVL propulsion system on the test stand, successfully accomplishing more than 220 transitions between conventional and STOVL operating modes. By the end of the year, in more than 500 trials on the STOVL engine run stand, transition times were repeatedly accomplished in one to three seconds.[39]

Figure 112: Boeing mechanics prepare to install the X-32B STOVL engine.

Low- and medium-speed taxi tests were completed on 10 January followed by the successful completion of the accelerated mission testing of the X-32B qualification engine on 15 January. The engine and its components were put through two full profiles of what the X-32B will do in flight test. All propulsion system components operated as predicted. On 7 March, the X-32B completed its maximum-thrust engine runs. Medium- and high-speed taxi tests were conducted on 26 and 27 March, respectively, in preparation for a first (conventional) flight the following day.

Figure 113: First phase of X-32B engine runs, 22 September 2000.

6.5 Lockheed Martin

6.5.1 Lockheed Design Evolution from ASTOVL to Concept Exploration Phase

During the ASTOVL studies, Lockheed matured their designs for their demonstration aircraft and for the PWSC. Additionally, Lockheed developed their LSPM to demonstrate their JAST concepts. A number of Small Scale Powered Models (SSPMs) were also tested to develop a basic understanding of the hover and transition regions. Although some phenomena can be scaled from small scale to full scale, the LSPM tests were necessary since it is not possible to simultaneously scale the jet buoyancy and entrainment effects. Prior programs (e.g. the USN XFV-12A ejector augmentor concept) showed that relying on small-scale data only can lead to serious difficulties in the development of STOVL aircraft. Comparison of the LSPM data to that of the SSPMs allowed a thorough assessment of scale effects.[40]

Figure 114: Lockheed ASTOVL Configuration 100

Lockheed continued to refine their ASTOVL design and continued SSPM and LSPM testing. Configuration 140 was used as the baseline for the initial model tests. Many of the features were similar to the Lockheed YF-22, including the basic wing geometry, the main engine inlet configuration, the internal weapons carriage concept, and the forebody/crew station layout. The major departures from the basic YF-22 were the use of a single F119-derivative engine (designated SE611A) and the use of canards instead of an aft tail. This planform provided an efficient means of trimming the aircraft across a wide range of Mach numbers when its function is coupled with a pitch vectoring nozzle and automatic camber control on the wing. The canards were unaffected by the complex jet interaction phenomena during STOVL operations as compared to an aft tail.

P&W and GE established during the ASTOVL studies that a variable cycle shaft driven lift-fan (SDLF) was theoretically feasible. However, there were practical concerns, such as the uncertainties associated with the weight of the shaft and gearbox that drive the lift-fan, and the ability of the engine control systems to synchronize the operation of the lift fan and the cruise engine. Phase II, therefore, was conducted to resolve these uncertainties. The Lockheed Skunk Works teamed with the Allison, P&W, and Rolls Royce engine companies to demonstrate the feasibility of the SDLF propulsion system by building a demonstrator engine and testing it in a LSPM (representing approximately an 89% scale of their SSF concept).[41]

Figure 115: Lockheed LSPM

The LSPM was powered by a Pratt & Whitney F100-PW-220 series engine with an Allison shaft-driven lift fan. Testing began at NASA Ames' Outdoor Aerodynamic Research Facility (OARF) in July 1995. In August, the model was modified to move the canards to the aft tail location to better represent Lockheed's new configuration. Outdoor testing resumed from September through December. From December 1995 through February 1996, the model was tested indoors at the 80 ft by 120 ft wind tunnel, also at NASA Ames.

Figure 116: Lockheed LSPM at the OARF

The evolution of the Lockheed ASTOVL design from Configuration 100 through 160 showed a reduction in performance, size, and technology requirements, resulting in decreased risk, weight and cost. The incremental reduction in size obviated the need for a larger core engine and enabled Lockheed to select the SE611 engine with a core common to the F119.

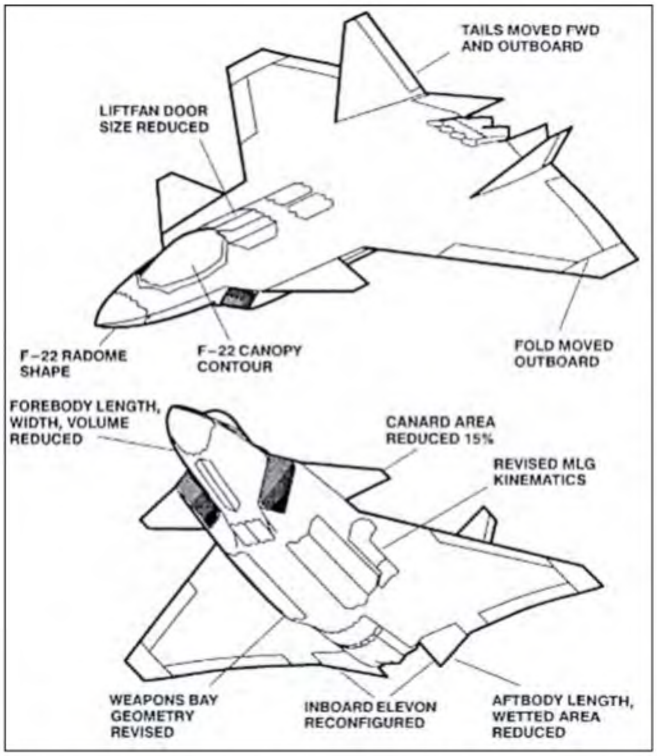

Figure 117: Lockheed Configuration 160 Illustration Describing Changes From Configuration 140.

Lockheed's original STOVL Strike Fighter and JAST Concept Exploration Phase design had a diamond wing with canard foreplanes for pitch control. During the JAST CDDR phase, this evolved to a conventional, tail-aft design to accommodate JAST requirements, in particular to improve carrier suitability characteristics.

Figure 118: Lockheed ASTOL/JAST Model in NASA Wind Tunnel Tests.

Lockheed's original SSF and JAST CE design had a diamond wing with canard foreplanes for pitch control. During the JAST CDDR phase, this evolved to a conventional, tail-aft design to accommodate JAST requirements, in particular to improve carrier suitability characteristics. The canard configuration offered the lowest possible empty weight, which was consistent with the original focus of the DARPA ASTOVL program. However, this configuration did not offer as much flexibility to meet JAST mission needs. In particular, the increased wing and tail size for a CV variant were more easily accommodated by a tail-aft configuration.

Figure 119: Initial Lockheed JAST Concept

The canard configuration offered the lowest possible empty weight, which was consistent with the original focus of the DARPA ASTOVL program. However, this configuration did not offer as much flexibility to meet JAST mission needs. In particular, the increased wing and tail size for a CV variant were more easily accommodated by a tail-aft configuration.

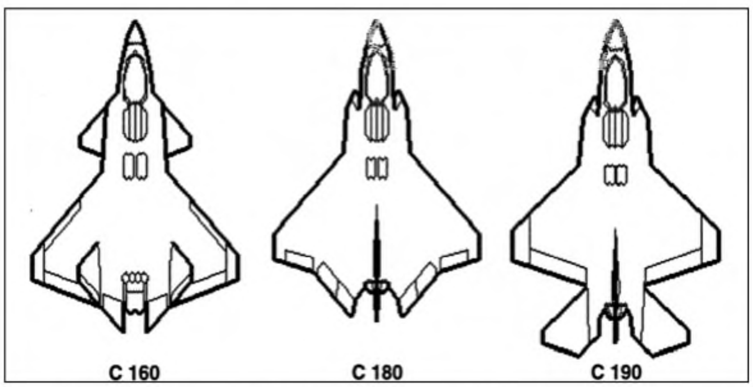

Figure 120: Additional Lockheed JSF Concepts.

Lockheed's STOVL variant was designed to use a SDLF to increase the total lift and to provide a portion of the lift forward of the aircraft center of gravity. The lift fan, located just aft of the cockpit, was driven by a clutch-operated, rotating shaft extending from the front of the main engine. For the main engine exhaust, a 3-bearing swivel nozzle provided the necessary downward thrust deflection for STOVL operation. The same nozzle was used for cruise and hover, but the vectoring capability was not used in up-and-away flight. Non-STOVL variants would not utilize thrust vectoring. In 1995, Lockheed Martin signed an agreement with the Russian Yakovlev Design Bureau and Pratt & Whitney signed one with the Soyuz Aero Engine Company for information on the supersonic Yak-141 STOVL fighter and its three bearing swivel duct nozzle.

6.5.2 Lockheed Design Evolution to Concept Definition Phase

Lockheed's original STOVL Strike Fighter and JAST Concept Exploration Phase design had a diamond wing with canard foreplanes for pitch control. During the JAST CDDR phase, this evolved to a conventional, tail-aft design to accommodate JAST requirements, in particular to improve carrier suitability characteristics. The canard configuration offered the lowest possible empty weight, which was consistent

with the original focus of the DARPA ASTOVL program. However, this configuration did not offer as much flexibility to meet JAST mission needs. In particular, the increased wing and tail size for a CV variant were more easily accommodated by a tail-aft configuration.

Lockheed's STOVL variant used a shaft-driven lift fan (SDLF) to increase the total lift and to provide a portion of the lift forward of the aircraft center of gravity. The lift fan, located just aft of the cockpit, was driven by a clutch-operated, rotating shaft extending from the front of the main engine. For the main engine exhaust, a 3-bearing swivel nozzle provided the necessary downward thrust deflection for STOVL operation. The same nozzle was used for cruise and hover, but the vectoring capability was not used in up-and-away flight. Non-STOVL variants did not utilize thrust vectoring.

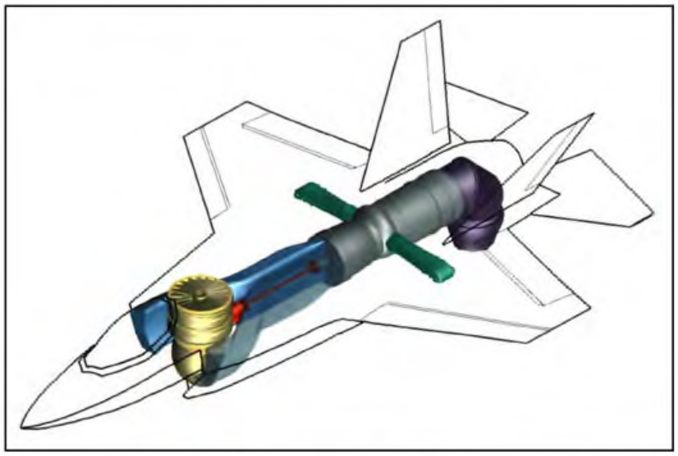

Figure 121: Lockheed Martin SDLF Powered Lift System

Additional Lockheed JSF design features included:

- P&W SE611 derivative of F119 engine
- Diverterless engine inlets
- Weapons bay in all variants sized to accommodate two 2,000-lb class weapons plus air defense missiles internally
- Common wing carry through structure in all variants

The Lockheed JSF is designed with diverterless engine inlets. The philosophy behind the diverterless inlet begins with high-speed flight. During high-speed flight, a very low velocity, low-pressure boundary layer of air builds up on the fuselage of a supersonic aircraft. If ingested, this air will lower the performance of the engine; therefore, supersonic aircraft have always employed some sort of boundary layer diverter system to prevent the boundary layer air from entering the inlet. Until recently, an inlet required a boundary layer diverter, essentially a gap between the aircraft body and the inlet that diverts the low-pressure boundary air that builds up on the fuselage and prevents this boundary layer air from entering the engine.

In September 1997, Lockheed Martin completed major CDA subscale and component tests. A high-speed inlet/forebody model was tested successfully in a transonic tunnel at AEDC. The test results indicated that the performance levels measured met or exceeded predicted levels and that the X-35 "bump" inlet design was effective in providing high quality airflow to the engine throughout the planned flight test envelope. A low-speed inlet/forebody model was tested in subsonic and supersonic wind tunnels at the NASA-Lewis Research Center in Ohio. The full range of X-35 STOVL operating conditions was modeled in these tests. Data analyses indicated robust performance and excellent engine/inlet compatibility.

An F-16 was then modified in 1996 at Lockheed facilities in Ft. Worth, to test the diverterless engine inlet concept, it was subsequently successfully flight tested at speeds up to Mach 2.[42] A visual comparison

of a normal F-16 inlet and the modified F-16 with the diverterless inlet is shown in Figure 122**.** Lockheed Martin engineers developed their diverterless inlet with a "bump" that acts as a compression surface with a forward swept aft-closing cowl.

Figure 122: An F-16 With a Diverted Inlet (left) and an F-16 With a Diverterless Inlet (right).

An overview of the design evolution of the Lockheed Martin concept is given in Figure 123.

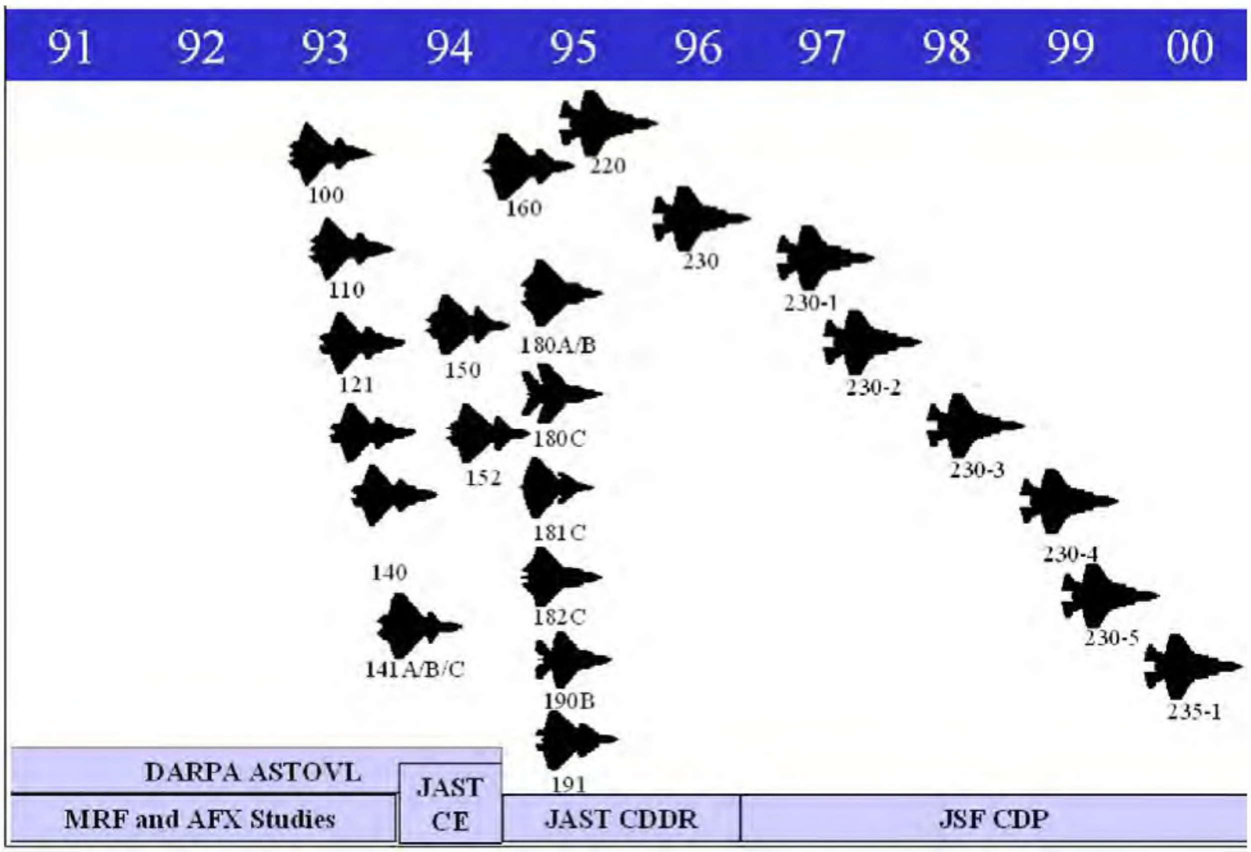

Figure 123. Lockheed Martin concept evolution.

6.5.3 Lockheed CDP Design Refinement

The Lockheed Martin JSF team includes Lockheed Martin Tactical Aircraft Systems (LMTAS) in Fort Worth, Texas, Lockheed Martin Aeronautical Systems in Marietta, Georgia, Lockheed Martin Skunk

Works, Palmdale, California, and teammates Northrop Grumman and BAE Systems.* Together the team is developing a highly common family of aircraft to meet the multi-service strike mission needs while accommodating unique service requirements. The service variants share the same fuselage with differences allowed for specific service needs such as Navy carrier and USMC STOVL operations. A diverterless supersonic inlet reduces the weight and complexity associated with conventional inlet concepts while reducing radar signature. All of the variants are powered by the SE611, a derivative of the F-22/F119 engine. The internal weapons bay is of a common size and configuration across the family. The wing carrythrough structure is common for all three versions with high lift additions along the wing periphery for the CV variant. Studies will determine the appropriate mission systems required on each aircraft.

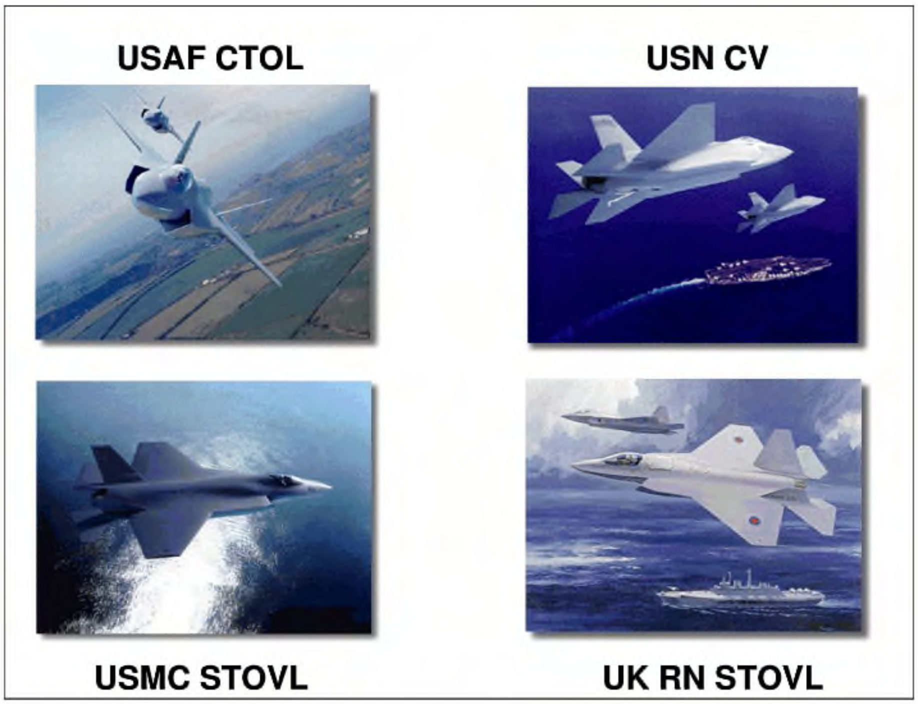

Figure 124: Lockheed Martin JSF Weapon System Concept

The STOVL variant uses the same SE611 engine as the CV/CTOL versions with modifications for power extraction to drive a lift fan for STOVL operations. The Shaft Driven Lift Fan (SDLF) concept, patented by Lockheed Martin, was successfully demonstrated through the large scale powered model (LSPM) described in Section 4.4.1. The STOVL variant also features a unique three bearing swivel duct (3BSD) nozzle. Lockheed Martin plans to perform unique demonstrations to reduce risk on their concept and is an active participant in JSF Tech Mat programs. According to Lockheed Martin, they selected the SDLF propulsion system for three primary reasons:

- The STOVL Lift Fan thrust can be de-coupled from the Pratt & Whitney cruise engine, thereby enabling the cruise engine to be appropriately sized for conventional flight;
- The significant amount of thrust augmentation obtained from the Lift Fan greatly exceeds the additional weight incurred; and
- The lower exhaust jet temperature and pressures result in a more benign ground environment during hover than that produced by direct lift. [43]

* Formed on 30 November 1999 when British Aerospace (BAe) merged with Marconi Electronic Systems (MES).

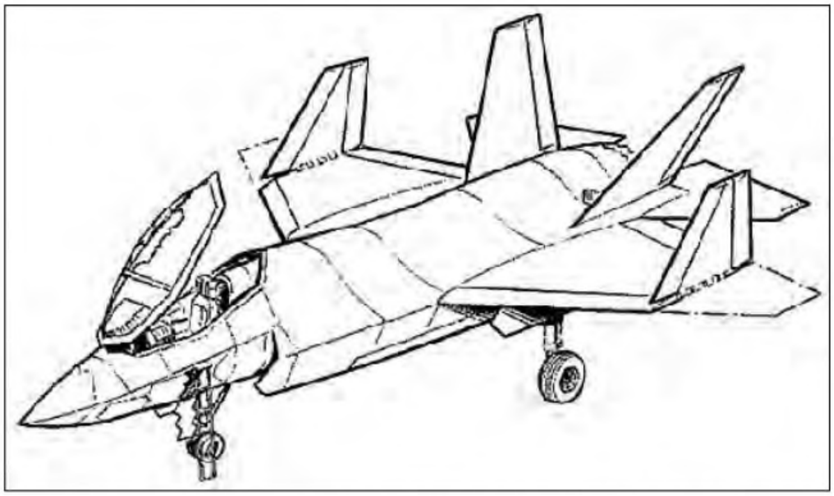

Figure 125: Lockheed Martin USN (230-3B) Variant Showing Wing Fold

Lockheed Martin successfully completed its Initial Design Review (IDR) in June 1997 in Ft. Worth, Texas. At the Paris Air Show, on 18 June 1997, Lockheed Martin announced teaming arrangements with British Aerospace (BAe). BAe chose to team with Lockheed Martin because it believed it could "'make a significant contribution' in many areas, but especially in the [STOVL] aspects of the JSF program."[44]

On 3 July, just two days after the FTC approved the Boeing/McDonnell Douglas merger, Lockheed Martin announced plans to acquire Northrop Grumman for $8.3 billion, and to bring Northrop Grumman onto their JSF team. The companies had planned to finalize the merger by the end of the first quarter of 1998.[45,46] However, an antitrust review by the U.S. Justice Department finally denied the merger. Northrop Grumman remains a member of the Lockheed Martin team and brings extensive experience in stealth, systems integration and carrier-based aircraft design.

[redacted] was named Vice President of Lockheed Martin and the Lockheed Martin JSF Program Manager on 5 February 1998. Lockheed Martin's JSF contract was increased by $6.2 million on 31 March 1998 to expand the scope of the Air Vehicle Prognostics and Health Management (AVPHM). The contract was again expanded on 1 April 1998 for additional funds for the JSF Integrated Core Processing Technology Demonstration.[47, 48] [redacted] was named Executive Vice President and General Manager of the Lockheed Martin Joint Strike Fighter in November 2000. [redacted] was appointed to developing the Lockheed EMD proposal.[49]

In August 1998, Lockheed Martin began wind tunnel testing at the National Aerospace Laboratory in the Netherlands. Testing of scale models were accomplished at NLR's 9.5 by 9.5-meter low speed wind tunnel beginning in August. The government of the Netherlands has made $75 million available for Dutch companies to use in pursuing technologies applicable to the JSF Program.[50]

The first Lockheed Martin full mission simulation took place in August 1998. The Northrop Grumman's Force Level Lab and the Lockheed Martin JSF Tactical Systems Simulation facility were connected via a secure link to Lockheed Martin's Battle Lab in Sunnyvale, California, and Northrop Grumman's JSTARS (Joint Surveillance Target Attack Radar Systems) manned simulation facility in Melbourne, Florida. In September 1998, Lockheed Martin completed a second pilot-in-the-loop simulation exercise, testing the integration of certain components of an innovative avionics system. During a two-week period, the high-fidelity laboratory simulations of avionics systems and pilot/vehicle integration were performed at the Northrop Grumman Pico Rivera, California, Force Level Laboratory. The recent simulation evaluated a high-resolution multi-purpose infrared sensor system and the integration of this information with data from other on-board sensors and from off-board sources. This simulation scenario

involved two JSF aircraft attacking various targets. Off-board data was data linked from an airborne warning and control aircraft and shared between the JSF aircraft in a total of 176 trial engagements using different combinations of variables. Preliminary results revealed emerging trends in the JSF's ability to detect and track threats that are consistent with expectations. During the next two years, more robust pilot-in-the-loop, multi-aircraft simulations will be conducted at the labs.[51]

In November 1998, Lockheed Martin completed 20 hours (36 flights) of flight testing with the Vectored-thrust Aircraft Advanced Control (VAAC) vehicle, a modified Harrier. Test pilots from Lockheed Martin, BAe, the USMC and the RAF participated in the evaluation. The flights were conducted in the UK with Britain's Defence Evaluation Research Agency (DERA) to support development of the Royal Navy STOVL variant. The evaluation program tested side-stick control of the aircraft in various STOVL tasks at flight speeds from hover to 200 knots. The testing confirmed that a side stick controller provides satisfactory control of a STOVL aircraft at low airspeeds.[52]

An initial PWSC workshare division was agreed to in late 1998, with Lockheed Martin responsible for the cockpit and wing design, Northrop Grumman leading fuselage development and British Aerospace designing the tail section. The workshare decision was based on the desire to minimize capital investments, take advantage of areas of proven quality and expertise, and minimize program management risk.[53]

Lockheed Martin held its X-35 Final Design Review (FDR) meetings at the Skunk Works in Palmdale, California, during July and August 1998, with the executive review on 25-27 August 1998. Prior to the reviews, Lockheed Martin had completed 90% of the drawing releases. The X-35 FDR marks the transition point between the completion of engineering design definition and the beginning of integration testing. The meetings evaluated Lockheed Martin's progress against 135 FDR criteria established at the beginning of CDP. A full-scale mock-up of the Lockheed Martin PWSC JSF design (Figure 126) was completed in September 1998.[54]

Figure 126: Lockheed Martin JSF Full-Scale Mockup

From December 1998 through April 1999, BAe conducted testing in its Acoustic/Thermal Facility at Brough, England, to assess environmental effects of the JSF propulsion system in the STOVL mode. The test program used a 1/15th-scale model of the X-35B, generating exhaust flows of the velocity and temperatures expected for the full-scale aircraft. This involved hundreds of measurements of velocities, temperatures, pressures and acoustic levels at many locations on and around the aircraft. From these data, engineers were able to assess the effects on the aircraft, ground personnel, ground equipment and landing surfaces. Afterwards, the 1/15th-scale aircraft model was slightly modified from the X-35B to the PWSC STOVL aircraft design, and tests at the BAe facility reconfirmed environmental effects to substantiate expectations that the Lockheed Martin JSF design will be operationally suitable. Larger-scale tests were also conducted in the United States.[55]

The PWSC aerodynamic designs (i.e. in wing-borne flight) were then tested in both low- and high-speed wind tunnels. Due to the commonality in the design of the three variants, the same basic 1/15-scale model was used for all testing, with different wing and tail surfaces and appropriate fairings attached to replicate the different variants. Approximately 200 hours of low-speed testing was conducted during August 1999 in the 16-by-23-foot Low-Speed Wind Tunnel at Lockheed Martin Aeronautical Systems in Marietta, Georgia. Testing was performed in both takeoff/landing and "up-and-away" configurations at speeds up to 200 kt. High-speed testing was conducted at the wind tunnel facilities of Veridian Engineering (formerly CALSPAN) in Buffalo, New York, and the Air Force's 16-foot Transonic Tunnel at Arnold Engineering Development Center in Tullahoma, Tennessee. More than 200 test hours were completed in the high-speed series through early October. High-speed testing was conducted in the speed range of Mach 0.6 to 1.6.[56]

In January 2000, STOVL jet effects testing was completed in the Netherlands and results were better than predicted. [57] In mi-April, Lockheed completed their final (proposal configuration, designated 235) 1/12 scale wind tunnel model and delivered it to AEDC for wind tunnel testing.[58]

In a series of piloted mission simulations conducted during early 1999 at the Tactical Systems Simulation facility in Fort Worth, Lockheed Martin evaluated multi-sensor techniques, enhanced target recognition capabilities and in-flight mission management algorithms. It is expected that this will significantly improve accuracy in weapons delivery. Operational military pilots participated in mission planning, tactics development and test execution and stated that these capabilities "allow pinpoint targeting accuracy." The tests replicated scenarios where the pilots attacked mobile ground targets defended by anti-aircraft weapons and surface-to-air missiles in varying terrain, allowing pilots to experience Lockheed Martin's JSF capabilities at a very high level of fidelity. Automated flight path capabilities were incorporated, demonstrating the systems' ability to successfully prosecute the right targets while remaining survivable in all parts of the mission.[59]

Lockheed's Full Mission Simulation in February 2000 allowed nine military pilots to fly over 40 hours in the JSF simulators during realistic combat tests designed to replicate the combat environment of 2010 with an intricate network of surface-launched and airborne threats. The 7,000 ft2 Virtual Battlefield Management Center includes two fully equipped JSF cockpit stations with all-aspect, high-resolution visual systems, plus four manned control stations for adversaries or additional friendly aircraft. A theater-style observation room provides real-time viewing by observers and can also be used for pre- and post-mission briefings. The test series simulated all JSF sensor systems. In addition to data from on-board sensors, the simulation integrated information from off-board sources to give the pilots maximum awareness of the combat situation. Full-mission simulation to this degree of complexity and realism is unprecedented so early in the life of a weapons system and is expected to save hundreds of millions of dollars in flight-testing costs over the life of the JSF.[60]

In early 1999, Lockheed Martin successfully completed a hardware-in-the-loop test of infrared signature and countermeasure concepts in the Air Force Electronic Warfare Evaluation Simulation (AFEWES) facility located at Lockheed Martin Tactical Aircraft Systems in Fort Worth, Texas. The objective of the test was to determine the effects of infrared signature and countermeasures on aircraft survivability. During each simulation, emissions from sources representing the target were projected onto an actual missile seeker head. Software models simulated the flight of the missile and the target aircraft during the encounter. From that, a determination was made on whether the missile would have hit or missed the target. The results from the AFEWES tests have been used by the Lockheed Martin JSF team to further enhance JSF survivability.[61] In April 1999, Lockheed selected Sanders/Litton Amecom to be the electronic warfare equipment supplier for its PWSC aircraft.

AFEWES features real-time, real-frequency, hardware-in-the-loop, operator-in-the-loop simulations of the latest array of threats with seekers in the infrared and radar spectrums. AFEWES is a government-owned, hardware-in-the-loop test facility managed by the Air Force Flight Test Center's 412th Test Wing

at Edwards Air Force Base, Calif. The facility provides a secure electronic combat test laboratory with a wide range of high-fidelity radar and infrared threat simulators. The controlled environment of the AFEWES allows a customer to test and retest systems and techniques at significantly lower costs than flight tests. [62]

Lockheed later completed evaluations of their JSF aircraft in defeating threat missile systems. In September 1999, more than 1,400 test runs were performed against air-to-air and surface-to-air infrared-guided missiles. More than 250 test runs, consisting of 1,500 radar-guided surface-to-air missile launch opportunities, were performed in December 1999. High-fidelity simulation-based tests were employed to help determine the best survivability and cost tradeoffs as the aircraft system design is refined. The JSF team used the tests to evaluate the survivability effects of the aircraft's signature, maneuverability and countermeasures systems against specific advanced threats. [63]

In early 2000, Lockheed completed the construction of a high-fidelity sensor integration facility, the JSF Mission Systems Integration Laboratory, which is being used to test sensor subsystems and their integration in the overall JSF avionics package. The facility included a full-scale mockup of the Lockheed Martin JSF aircraft mounted on a tower. The mockup had embedded sensors, which are connected to commercial off-the-shelf (COTS) processors and a remote cockpit station for man-in-the-loop operation. The JSF sensor integration facility is used to evaluate individual sensor subsystems, both hardware and software, and the functional integration in the overall JSF mission system, or avionics, architecture. Suppliers can evaluate data on their subsystems at several stages in the design process to refine their hardware and software, as well as verify and update computer simulation models of their subsystems. The 40-foot tower with the rotating mockup was designed for sensor and aperture integration and allows collection of free-space data in a real-world environment. The tower's location provides unrestricted views of flights at Dallas-Fort Worth Airport 20 miles away, the adjacent Naval Air Station Fort Worth Joint Reserve Base and several other nearby airfields. Also, a variety of surface "targets" are within direct view, including traffic on two local interstate highways and recreational boats on a neighboring lake. During EMD, the sensor facility would be expanded to test all mission systems prior to evaluation on the JSF flying test bed and on JSF EMD aircraft. The facility would also be used in development of the JSF's "information fusion" capability, which will correlate data from various on-board sensors together with off-board information received via a high-volume data link.[64]

Figure 127. Lockheed Martin Mission Systems Integration Laboratory. [65]

In mid-1999, the Lockheed Martin team began modifications on a Northrop Grumman-owned BAC 1-11 flying avionics test bed – called the Cooperative Avionics Test Bed (CATB) – to test prototype multi-sensor JSF avionics under real-life conditions that are difficult to produce in simulation. The BAC 1-11 was used as the YF-23 avionics test bed as well as for the development of the B-1B, F-16, F-22 and other radars. Flight testing of the Lockheed Martin prototype JSF active electronically scanned array (AESA) on the BAC 1-11 began in late February 2000. Airborne testing was required to reduce risk by factoring in dynamic, real-world effects on sensor performance that cannot be adequately reproduced in simulations or ground testing. The advanced-technology prototype avionics systems installed in the CATB include the Northrop Grumman multimode radar and distributed infrared sensor system, the Kaiser helmet-mounted display and a Lockheed Martin processor. The infrared sensor system, along with the helmet-mounted display, allows the pilot to "look" in any direction to spot targets and threats, day or night. The helmet-mounted display provides the pilot with off-boresight target/sensor cueing capability, as well as other data traditionally provided by a fixed head-up display. Other JSF sensors and systems flight tested on the BAC 1-11 include a long-based interferometer (Lockheed Sanders/Litton); an electro-optic targeting set (Lockheed Martin Electronics & Missiles); a distributed aperture infrared system (Northrop Grumman's Electronic Sensors and Systems Sector); and a registration/geolocation product (Harris). The JSF will be able to correlate target data from on-board sensors and off-board sources.[66, 67]

Figure 128. Northrop Grumman BAC 1-11 avionics flying test bed. [68]

In October 2000, Lockheed successfully demonstrated all-weather precision targeting and combat identification techniques for both fixed and mobile targets. In a cooperative engagement between a Joint Surveillance Target Attack Radar System (Joint STARS) aircraft and the CATB, the Lockheed Martin JSF mission systems on the BAC 1-11 acquired and derived targeting data of high-value stationary and moving targets during simulated attacks at Aberdeen Proving Grounds, Md. [69]

The first Joint STARS/JSF CATB scenario demonstrated an all-passive cooperative engagement, with the JSF executing a "silent ingress" (radar and communications systems switched off) and receiving all target-acquisition information from Joint STARS at long range. Flying at typical operational ranges and altitudes during the demonstration, and using high-value relocatable moving targets (tanks, supply convoys, missile launchers, etc.), Joint STARS detected and relayed the information via a real-time data link to the JSF CATB avionics system. JSF CATB used the data to cue its electro-optical targeting system (EOTS) to passively locate and track the moving targets for pilot identification and weapon delivery at standoff ranges. [70]

In the second scenario, Joint STARS detected the high-value moving targets at long range and relayed the target location to the JSF CATB. Joint STARS target data then cued JSF's all-weather, long-range Active Electronically Scanned Array (AESA) radar, which used its simultaneous synthetic aperture radar/ground-moving-target indication (SAR/GMTI) mode to re-acquire and locate the targets with the same precision as Joint STARS. The AESA then increased the SAR/GMTI resolution for a precision single-ship attack. The demonstrations merged the data from Joint STARS with the JSF CATB, resulting in greatly improved targeting. [71]

When the CATB evaluation program was completed in September 2000, the BAC 1-11 had logged more than 100 hours of flight time testing Lockheed Martin JSF mission systems. Three scenarios defined the test environment: air interdiction, close air support and strategic attack. The avionics package showed effective warnings against multiple threats while simultaneously attacking designated targets. The tests also emphasized how the fusion of data from the integrated mission system enhances JSF survivability and

lethality. The JSF mission system demonstrated precision engagement and identification of challenging targets in urban areas. The fusion of on-board and off-board imagery also enhanced target acquisition, identification and precise location.[72]

In September 1999, Lockheed Martin shipped a full-scale pole model to their remote Helendale Measurement Facility in California, in preparation for extensive radar signature testing. There it underwent final assembly with the wing, horizontal tail and vertical tail mating in late October. The model, called "SigMA" (Signature Measurement Aircraft), is the culmination of a series of signature demonstrations intended to validate affordability and reduce risk for the EMD. The primary purpose of SigMA is to demonstrate RCS compliance of the PWSC design and validate the RCS computer modeling and simulation techniques the PWSC design team uses to refine the aircraft configuration. The testing will measure aircraft RCS and the performance of various antennas on the aircraft and will demonstrate the robustness of supportable low observable (SLO) materials. SLO demonstrations will be performed on several doors and panels on the model. RCS measurements of deliberately damaged and repaired components will be made to determine the effect of defects and the effectiveness of repairs. The model is of unprecedented fidelity at this stage in development, including removable doors and access panels, a transparent canopy, cockpit details, lights, air data probes, engine components, realistic edges, repositionable control surfaces, antenna apertures, radar array, and flight-capable radomes.[73]

The Lockheed JSF team began SigMA RCS testing in February 2000. The testing measured aircraft RCS and the performance of various antennas on the aircraft. Tests also demonstrated the robustness of SLO materials and their ease of repair. After baseline testing, several doors and panels were intentionally damaged and then repaired, and RCS measurements were made to determine the impact of defects and the effectiveness of repairs.[74] Tests on SigMa completed in late September validated the stealthy shape, the resilience of its LO materials and previewing its cost-savings potential. The inflicted damage – more than three dozen significant defects – represented in type and frequency the cumulative effect of more than 600 flight hours of military aircraft operations. When engineers overlaid the RCS curves of the undamaged, damaged and repaired configurations, they found it difficult to determine which curve represented which configuration. Shop personnel fixed all the damage in a single eight-hour shift. Similar repairs to a legacy B-2 would have required more than 72 hours.[75]

Figure 129. SigMA RCS testing at Lockheed's Helendale facility. [76]

In Fall 1999, Lockheed Martin evaluated the combat survivability of its JSF design through ballistics testing of the wing. The multiple spar design contained damage caused by even the most severe ballistic threat tested. Prior to the test, advanced analytical simulation tools were used to predict the structural response of the wing during the ballistic event. The actual test then confirmed the accuracy of the simulation. To accurately assess the physical damage to the wing structure, post-test analysis was conducted with Lockheed Martin's Laser Ultrasonic Test System. This production inspection system required no hard tooling and had a total setup time of less than 10 minutes. A complete ultrasonic scan and analysis of the wing structure was completed in less than 90 minutes, as opposed to the 36 hour industry standard. This demonstration increased confidence that field inspection and maintenance of an operational JSF could be completed in minutes instead of days.[77]

In early October 1999, Lockheed Martin announced the final team work-share decisions for EMD. Lockheed Martin, led by LMTAS, pledged to commit the capabilities and strengths of the entire corporation, across four major business areas and some 17 lines of business. Lockheed Martin's contribution will include application of lean manufacturing and best practices, component manufacturing and mate through delivery, weapon system integration, low observables expertise, composite technology applications and mission systems development. Northrop Grumman's Integrated Systems and Aerostructures sector is responsible for detailed design and integration of the JSF center fuselage and weapons bay door drive system, including installation design and integration of installed subsystems; development of a substantial portion of mission systems software; ground and flight test support, including conducting the air vehicle drop test program and fuel system testing; development of the software element of the flight control system for the carrier variant; development support in the area of signature/low observables; and support of modeling and simulation activities including pilot-in-the-loop simulations. British Aerospace is responsible for detailed design and integration of the aft fuselage, the horizontal and

vertical tails (excluding edges), and wing folds for the UK STOVL and CV variants; design and procurement lead of the fuel system for all variants; development of a significant portion of the cockpit integration, including design and procurement lead of the crew escape and life support systems; STOVL flight test support; STOVL static and durability full-scale structural testing; systems engineering for STOVL operations and reliability, maintainability and supportability; air vehicle and airframe integration, including STOVL wind tunnel testing; STOVL control laws; development support for the propulsion integration; development support for the mission systems software, including UK stores fire control, UK external communications and structural prognostics health management; and development support to the support and training systems.[78] A detailed listing of the intended suppliers and subcontractors is:

Suppliers

- [redacted] (Nashua, NH)/Litton Amecon (College Park, MD): Electronic Warfare and Counter Measures (EW/CM)
- Northrop Grumman Electronic Sensors and Systems Sector (Linthicum, MD): Radar
- LM Missiles and Fire Control (Orlando, FL)/NG ESSS (Linthicum, MD): Electro-Optical - Distributed Aperture System (EO-DAS)
- Kaiser Electronics (San Jose, CA): Multifunction Display (MFD)
- [redacted] (Torrance, CA): Wing Fold Actuation
- Honeywell (Torrance, CA): Power Thermal Management System (PTMS)
- Sundstrand (Rockford, IL)/[redacted] (Cheltenham, UK): Electrical Power System (EPS)
- TRW (Rancho Carmel, CA)/Rockwell Collins (Cedar Rapids, IA): Communication, Navigation, Identification (CNI)
- VSI (San Jose, CA): Helmet Mounted Display (HMD)

Subcontractors

- Moog (East Aurora, NY)/Parker (Irvine, CA): Flight Control Activators (FLCS)
- BAE Systems (Rochester, Kent, UK): Active Inceptor System (AIS)
- National Aerospace Laboratory (The Netherlands): Embedded Training Systems
- LM Missiles and Fire Control (Orlando, FL)/NG Electronic Sensors and Systems Sector (Linthicum, MD)/BAE Systems (Edinburgh, Scotland) Electro-Optical - Targeting (EO-TS)
- Harris Corp (Palm Beach, FL): Common Resources
- Rolls-Royce (Bristol, UK): Roll Off-take Ducts
- Raytheon TI (Plano, TX): Integrated Core Processor (ICP) (25%)
- L-3 Communication (Camden, NJ): ICP Panel
- Moog (Torrance, CA)/Curtiss-Wright (Fairfield, NJ): Leading Edge Flap Drive (LEFD)
- LM Information Systems (Orlando, FL): Trainers/Simulators
- United Technologies Pratt & Whitney (W. Palm Beach, FL): Engine
- Fokker-Elmo (The Netherlands): Power Panel, Electrical Distribution Unit, ROI Wiring
- Cytec Fiberite (Greenville, TX / Wrexham, UK): Composites
- Signaal (The Netherlands): Electro-Optical Core
- BF Goodrich (Cleveland, OH): Landing Gear System
- EDO (North Amityville, NY): Stores and Release System
- LM Tactical Defense Systems (Eagan, MN): Integrated Core Processor (ICP)
- Lucas Aerospace (Utica, NY): Driveshaft
- Lucas Aerospace (West Middleton, UK): Lift Fan Actuation Control
- Allison Engine Co. (Indianapolis, IN): Lift Fan Assembly
- Fokker-Space (The Netherlands): Embedded Trainers/Simulators
- Fokker-Aviation (The Netherlands): Airframe Fabrication
- Hexcel (Salt Lake City, UT): Carbon Fiber

- General Electric Aircraft Engines (Cincinnati, OH): Alternate Engine
- LM Control Systems (Johnson City, NY): Vehicle Management Computer
- TNO (The Netherlands): Advanced Algorithms

Lockheed Martin's 230-5 PWSC configuration was designed to meet the draft JORD requirements. The lift fan nozzle was redesigned and the inlets are smaller and lighter. Compared to 230-4, the 230-5 design has a slightly larger main wing to be capable of 9 *g* of loading: from 38.2 m^2 to 42.7 m^2 for the CTOL and STOVL and from 55.7 m^2 to 57.6 m^2 for CV.[79] The three service variants are highly common: 80% commonality between the CTOL and STOVL, and 70% commonality between the CTOL and CV versions.[80] Lockheed's 235 design was tailored to meet the refinements of the final JSF ORD.

Figure 130: Lockheed Martin JSF PWSC Characteristics

Lockheed has conducted a number of unique Tech Mat efforts to develop and demonstrate advanced technologies planned for EMD. Lockheed's Airframe Affordability Demonstration (AAD) program exhibited substantial reductions in span time and labor required for design, tooling, fabrication and airframe assembly. In August 1999, Lockheed performed an assembly demonstration on the wing carry-through structure of the JSF CV variant. The assembly took less than an hour, compared to several days using traditional methods, and reduced tooling by 95%. Using the same work cell, hand tools and procedures, workers assembled the similar wing carry-through structure of the STOVL variant in mid-October. The loading of the STOVL component took less than 30 minutes to complete, representing reductions of 33% in span time and 55% in man-hours, compared to the earlier event. Huge savings are expected in production as a result of the program and the commonality between variants.[81]

Besides demonstrating commonality, the AAD program also uses technological innovations to reduce the time and cost of manufacturing. For instance, an advanced drilling system called the JSF Gantry Applied Drilling System (JGADS) showed that it could significantly reduce manufacturing time and costs in a lean production environment.[82] And an automated fiber-placement process demonstrated substantial cost and schedule savings in production of the aircraft's composite upper wing skin, as shown in Figure 131. Advanced stiffening methods also resulted in a weight savings of 11%.[83]

 ~~FOR OFFICIAL USE ONLY~~

Figure 131. Upper wing skin fabricated by an automated fiber placement process.[84]

Another component of the AAD initiative uses a process called Variation Management provides significant savings through reductions in engineering changes, tooling, and scrap and rework. Variation Management reduces assembly variation during the design and manufacture of products. The initial phase involves iterative steps to understand requirements, focus emphasis and use process-capability information to predict the outcomes of assembly and design concepts. Design and assembly options can then be compared and improved before entering production.[85]

In late 2000, Lockheed demonstrated the use of an advanced resin transfer molding (RTM) process to fabricate a unitized all-composite component representing the X-35 vertical tail. Compared to traditional designs, the unitized tail structure was cured in a press as a single component. The RTM process reduced the part count from 13 to one and eliminated more than 1,000 fasteners. The corresponding manufacturing costs are reduced by more than 60%. The project also demonstrated that modeling of the resin flow can accurately identify preferred injection sites and sequences to assure proper impregnation throughout the component. Using the optimum model prediction resulted in complete mold filling, i.e., no dry spots and significant benefits to quality and production cost. The vertical tail is one of the largest and most complex composite components ever produced using the RTM process. The tail measures 12 ft along the leading edge and weighs almost 200 lb. The skins are composed of more than 100 plies and vary in thickness by a factor of four from root to tip. Fourteen unique, complex mandrels having continuously variable cross sections were over-braided to create the internal structure.[86]

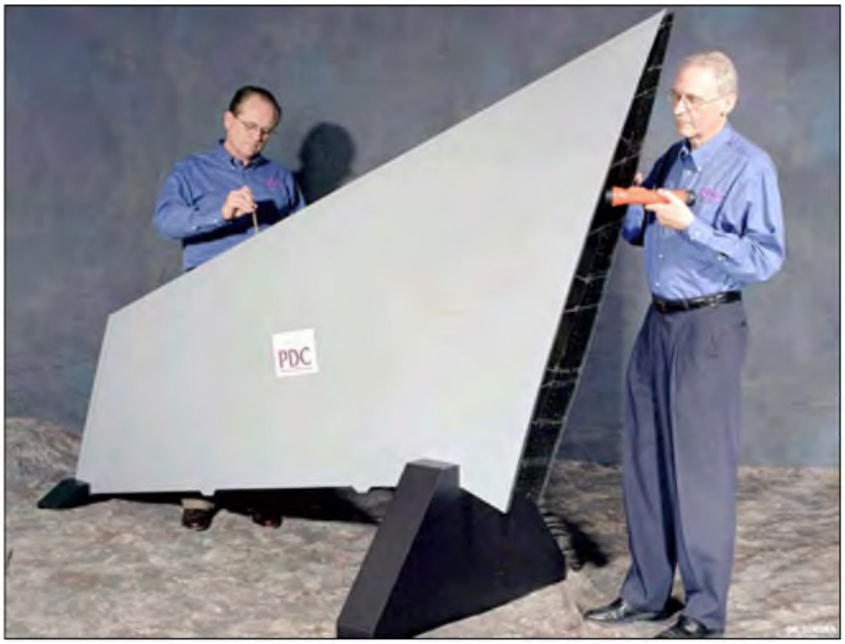

Figure 132. Unitized RTM composite piece representing a vertical tail. [87]

6.5.4 Lockheed Propulsion System Development

Lockheed Martin held their Lift System PDR on the Rolls-Royce roll post ducts and nozzles and the 3BSD on 7-8 May 1997. Although the actual contract between Lockheed Martin and Allison[*] for the Lift Fan development was not signed until 13 June 1997, the Lift Fan PDR was held on 27–30 May 1997 to assess the CDA Lift Fan concept for flight test, evaluating technical progress, technical adequacy, and risk mitigation. Since Lockheed Martin funded RR through P&W for the roll posts and the 3BSD was designed by RR as a sub-contractor to P&W through the government contract, the review was held at Pratt & Whitney's West Palm Beach, Florida facility. By September 1997, Pratt & Whitney and Rolls-Royce had completed scale model testing of the 3BSD and nozzle assembly at NASA Langley in Virginia.

During the summer of 1997, Allison conducted testing of a model of the Lift Fan nozzle at the NASA-Lewis Powered Lift Facility in Ohio. Test results validated computational fluid dynamics (CFD) predictions of exhaust nozzle performance. B.F. Goodrich conducted testing of the Lift Fan clutch being developed under a subcontract to Allison. Testing demonstrated high speed clutch engagements representative of X-35 STOVL operating conditions. A very favorable clutch plate wear rate translated into a clutch plate life of over four times the X-35 flight demonstration requirement.

During 1998, additional Lift Fan component tests—clutch, gearbox and fan—were conducted (Figure 133). Testing began on 8 May 1998 on the clutch rig, followed by the fan rig on 10 June, and the gearbox rig on June 19. The mechanical and aerodynamic performance was in line with the predicted results.[88] The first test article, Lift Fan #1, was completed and shipped to Pratt & Whitney in October 1998 (see Section 5.4.1). The Lift Fan was first driven by the SE611 STOVL engine on 10 November 1998 and operated at 100% speed for the first time on 22 November.[89]

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[*] Renamed Rolls-Royce Allison in 1998.

Figure 133: Testing of the Fan Rig for the Allison Lift Fan Began in June 1998

The first flight weight unit, Lift Fan #2A, was completed in June 1999 and shipped to Pratt & Whitney for testing with the engine. Testing of the propulsion system is covered in the following section, 5.4.1. Lift Fan 3 was completed shortly thereafter, with testing beginning in the Fall.

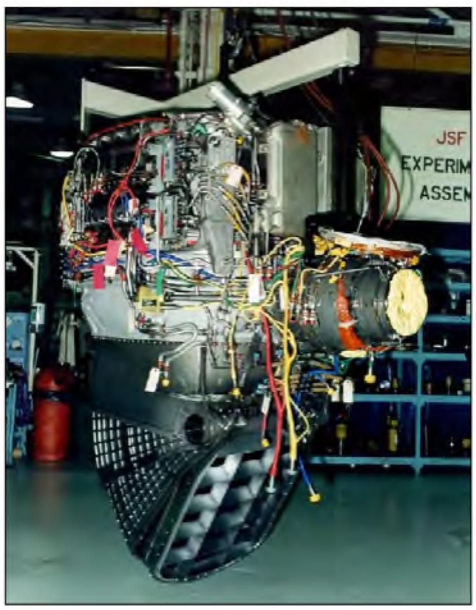

Figure 134: Lift Fan 2A upon completion in June 1999

On 28 January 2000, during steady-state full-power testing of the JSF119-611 engine at Pratt & Whitney, Lockheed demonstrated that the full-up STOVL propulsion system exceeded vertical lift operational thrust requirements. The vertical thrust was measured from all four "lift posts": the Lift Fan, the three-bearing swivel duct exhaust and the two roll off-takes. Also noted during the tests was the significant noise drop with the Lift Fan engaged. Since the Lift Fan is powered by a shaft from the engine, the turbine extracts more work (and therefore heat, noise and velocity) from the engine exhaust when the Lift Fan is engaged.[90]

Despite numerous oil leaks, vibration problems, and bearing difficulties, the Lift Fan testing finally was able to proceed relatively smoothly after mid-2000. In early December 2000, Lockheed announced that the Lift Fan had undergone 11.7 hours of uninterrupted testing, without anomalies and met all test objectives. The Lift Fan successfully completed 23 dynamic clutch engagements at engine speeds higher than those planned for flight test.[91]

In September 1997, Lockheed Martin completed major CDA inlet subscale and component tests. A high-speed inlet/forebody model was tested successfully in a transonic tunnel at AEDC. The test results indicated that the performance levels measured met or exceeded predicted levels and that the X-35 “bump” inlet design was effective in providing high quality airflow to the engine throughout the planned flight test envelope. A low-speed inlet/forebody model was tested in subsonic and supersonic wind tunnels at the NASA-Lewis Research Center in Ohio. The full range of X-35 STOVL operating conditions was modeled in these tests. Data analyses indicated robust performance and excellent engine/inlet compatibility. An F-16 inlet was also modified to model the X-35 inlet and flight tested up to Mach 2.[92]

6.5.5 Lockheed CDA Assembly

Lockheed Martin began fabrication of their first CDA airframe components in October 1997. By the end of 1997, they had made over 30 parts, and had received two inlet ducts (one for testing and one to be used on an X-35 CDA) from subcontractor Alliant Techsystems.

Lockheed began assembly of the first X-35 airframe on 21 April 1998, and initial testing of the flight control software began on 22 April. The engine inlet duct, built by Alliant Tech Systems, was installed in the assembly tool at the Skunk Works in Palmdale, California on 9 July 1998. On 17 August 1998 the main wing carry-through bulkhead was installed. This titanium bulkhead is the largest one-piece bulkhead designed and built for the X-35 CDA. Construction was also completed on the composite skins for the upper and lower surfaces of the X-35’s wings as well as over 80 composite pieces for the aircraft.[93]

The two Lockheed Martin CDAs will be flown as three aircraft types. Ship 301 will begin life as the X-35A CTOL aircraft, but, after initial testing, it will be fitted with the lift system components (i.e. the Lift Fan system, roll ducts, three bearing duct, doors, and control logic) required to demonstrate the STOVL objectives. The second aircraft, Ship 300, will demonstrate low-speed flying qualities necessary for landing on an aircraft carrier. Originally, Ship 300 was to be the STOVL demonstrator, and the CTOL version was to be modified to the X-35C naval version by adding larger control surfaces and a larger outboard section on the wing. In the May 1999 replan (discussed in Section 5.1.5), however, Lockheed Martin was able to eliminate the procurement of a set of control surfaces, since the CTOL and STOVL versions have the same basic planforms. The fact that Lockheed Martin “swapped half of one airplane with the other”, and the fact that the CV CDA could be retrofitted with the STOVL lift components, if necessary, highlights the commonality of the JSF CDA design (the lift fan bay, however, will not be common to the production CV and CTOL aircraft).[94]

During 1999, steady progress was made on assembly of the X-35, as well as refining and verifying the PWSC configuration. In January 1999, Lockheed Martin had the inlets in the fixtures and a few of the major bulkheads in place. About 10 assembly workers were working one shift at their Palmdale, California, Building 602 facility. By early February, the assembly effort dramatically accelerated to a second shift working seven days a week to work on the two CDAs.[95]

The airframe structure is composed of dozens of large, single-piece bulkheads. In the past, some of the bulkheads would have been built from 100 or more separate parts. Although it takes more time to fabricate the bulkheads, it requires less time to assemble them and they produce a stronger structure, for a net savings in cost and weight. The bulkheads were fabricated from either aluminum or titanium. The wing skins are mostly composite. Titanium is also used for frames and skins in portions of the airframe exposed to high temperatures or jet exhaust noise, particularly in the aft section. The majority of the aluminum machined parts were made at LMTAS. All the composite parts and some of the titanium frames were manufactured at the Skunk Works. Other suppliers fabricate the remainder of the titanium parts.[96]

The aircraft are being assembled in three large fixtures: one fixture was used for the cockpit section, a second was used for the mid-fuselage, and the third and largest fixture was used for the wing carry-through and the aft sections. This fixture was also used to mate the front and rear sections of the airframe. The inlets

were the first parts in the fixtures, with the rest of the mid-fuselage assembled around them. After installing the inlets in the fixtures, keelsons (the structural members that run from front to back, supporting the landing gear bay) were installed next. The rest of these two sections were built out from the center, with the skins installed last.[97] The cockpit section of the X-35A was joined with the mid-fuselage section on 15 April 1999. These two combined sections, with a combined length of over 34 feet, were joined with the wing carry-through structure the following month. The work crew then began installing major aircraft subsystems and crew station equipment. This was followed by fuel tank sealing and the installation and checkout of additional subsystems. The work was performed with smaller crews than originally planned and with minimal tooling and equipment, executing the assembly process that had previously been modeled in a CATIA 3D solid model virtual environment.[98,99]

Figure 135: X-35A Forward Fuselage section (April 1999)

Assembling the wing carry-through, the section between the mid-fuselage and the aft section began with the outer portions of the wing held precisely in the fixture. The forward and aft spars (structural members that span the wing from the fuselage out) were installed first. The major wing load carrying bulkheads were positioned in the fixture, then the rest of the spars were installed. The skins went on from the outboard wingtip to the center. The aft tail boom sections are being assembled separately and will be attached to the back of the wing carry-through section.[100]

Lessons learned during manufacturing of the X-35 are transferred through reviews to the rest of the Lockheed Martin JSF team for use in designing the PWSC aircraft. X-35 design features such as structural materials, developmental testing techniques and the physical integration of key air vehicle characteristics, as well as the overall JSF aero-propulsion analyses and test programs, were assessed to refine plans for upcoming phases of the program.[101] The JSF assembly team in Palmdale is also experiencing an improving learning curve as it builds the second airframe. Installing and trimming the inlet ducts in the mid-fuselage took several weeks the first time, while the same effort for the second airplane required only four days.[102]

The X-35A CDA moved from assembly tooling to the factory floor on 18 September 1999 (shown in Figure 136), to allow installation of control surfaces, actuated doors and the landing gear. The landing gear were installed and static load tests conducted in mid-October. By this time, the second demonstrator aircraft, the X-35C, was also in the assembly phase; installation of the wing carry-through and forward fuselage segments in the assembly tool were complete. System installations and final mate occurred in late October, and the X-35C joined the X-35A in system check-out tests by year-end.[103] Once the CV variant is

completed, it will be placed in a test fixture for structural proof testing to 100% of its design load. Since this is a demonstrator program, there is no static-fatigue article: Lockheed Martin is conducting the proof test to 100% load, but will only fly up to 80% of the design loads.[104]

Figure 136: X-35A Moves to the Factory Floor (September 1999)

A laser positioning system has been used to track the precise location of pieces within the fixtures. When the aft section and the wing carry-through section were first brought together, they lined up within 0.003 in. Downloading computer-based design information directly to numerically controlled machinery to fabricate parts eliminates imprecise and labor intensive steps. Tubing on the X-35 aircraft, for instance, was produced directly from digital descriptions of tubing routes. In the past, a mockup of the airplane was used to tack welded bits of tubing together to describe a particular tube; that tube was then used as a master to build a weld fixture.[105]

As with most demonstrator aircraft, the Lockheed Martin JSF demonstrators borrow many components from existing aircraft. The environmental cooling system is from the F-18E/F; the airframe-mounted accessory drive is from the B-2; the Upco ejection seat is the same one used on the Harrier AV-8B; the multifunction displays, produced by Avionic Displays Corporation, are from the C-130J; the head-up display is being developed for the Korean Air Force KTX-2 program; and the flight test nose boom is from the X-31. The nose landing gear is from the F-15E and the main landing gear is a 1990s update of the gear on the 1950s A-6 Intruder. The main gear had to be redesigned, however, because the 1950-vintage structural analysis and testing were not up to today's standards. The gear on the production aircraft will look similar, but will be tailored to be more compatible with the weapon bays.[106]

Figure 137: X-35A CDA (December 1999)

On 9 December 1999, Lockheed Martin installed the first JSF119-611 flight engine in their X-35A CDA at Lockheed Martin Skunk Works, Palmdale, California. Installation was completed in only three hours, including the time spent confirming procedures and documenting interfaces. The YF001 engine was installed for integration tests with the aircraft systems, including confirmation of engine and X-35 interfaces: all external plumbing connections, data communications and electrical checks. Tests also included installation and alignment of the airframe-mounted auxiliary drive unit and its power takeoff shaft. The engine was then sent back to Pratt & Whitney for system check-out tests.[107]

Figure 138: Engine Fit Check in X-35A (Dec 1999)

By the end of the January 2000, the X-32A had completed hydraulic gear swings, fuel tank electrical checkout and speed brake assemblies.[108] The four horizontal and vertical tails were then installed.[109]

Figure 139. X-35A airframe assembly was completed in March 2000. [110]

The Lockheed engine altitude qualification testing at AEDC was completed in February 2000, and the YF001 engine was delivered to Palmdale on 14 February.[111] The initial CTOL Flight Clearance Request Letter Data Package was delivered electronically to the JSFPO on 15 February. [112] A successful CTOL First Flight Readiness Review (FFRR) completed was completed the following month, the pacing item being software verification and validation.[113] Representatives from the JSF Program Office engineering teams, independent review team and safety review board validated the Lockheed Martin JSF design as safe and ready for flight, following completion of remaining ground testing. The CTOL Propulsion Flight Certification Review was successfully completed in early May.[114] The aircraft was painted in early June, as shown in .

Figure 140. X-35A after painting (June 2000). [115]

Meanwhile, the CV CDA (X-35C) was making steady progress with manufacturing. Subsystem installation and checkout proceeded at a much-improved rate over the earlier CTOL aircraft. All fits and interfaces were also improved. [116] The two aircraft continued their assembly efforts in parallel. The CTOL/STOVL CDA (X-35A) began structural coupling testing on 20 April 00 and completed engine installation the following day.[117] Ground Vibration Testing (GVT) was finished on 7 May. The X-35C was simultaneously being installed in the reaction frame for structural proof testing preparing for load testing. [118]

The X-35C completed structural loads testing in June 2000. The structural testing verified the X-35's ability to withstand the rigors of flight testing. A test fixture with 90 hydraulic actuators applied stresses to different parts of the airplane to simulate in-flight aerodynamic pressure loads on the aircraft (see Figure 141). Because the variants are structurally very similar, the X-35C load-test results apply to all three concept demonstrator variants. The aircraft was tested to 100% of design limit load, minus 3 gs and plus 8 gs: the wings were stressed to carry about 180,000 pounds, or the weight of 50 mid-size automobiles. Test conditions also included wing torsional testing that represents aircraft rolling maneuvers. Proof-of-operations tests also confirmed the control surfaces would not bind against the aircraft structure during full control surface deflections while the aircraft is in maneuvering flight. Testing also included operation of the propulsion doors for the X-35B STOVL variant. [119]

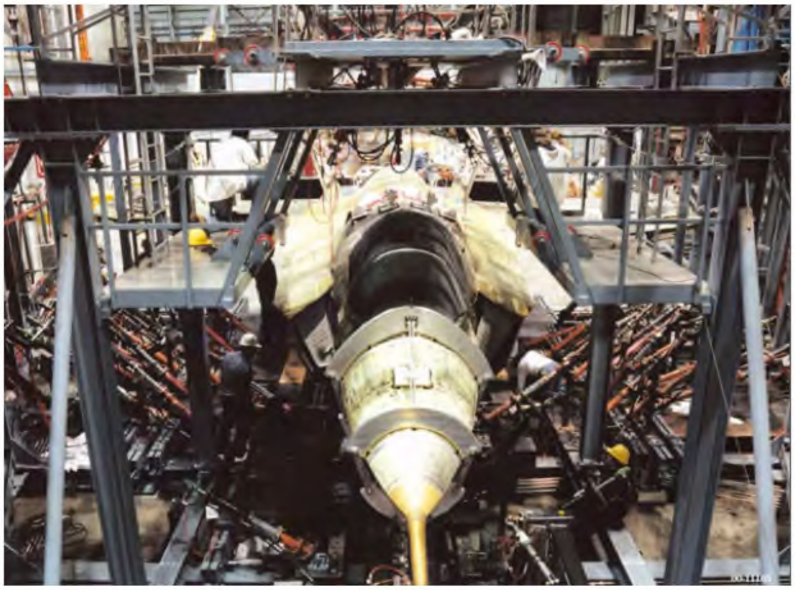

Figure 141. X-35C undergoing structural loads testing. [120]

Problems with X-35A APU bay overheating were corrected in early June. With the installation of the CDA horizontal stabilizers, the X-35A assembly was complete. [121] Hydraulic system overheating was still a problem, and hardware modifications were required for flight. This caused several weeks of delays to first flight.[122] In the meantime, the X-35A successfully completed engine integration testing at all power settings (idle to full afterburner).[123] Finally, all modifications, repairs and maintenance activities required to support first flight in mid-October. Engine runs were conducted on 12 October 2000. Taxi and flight testing began the next week, as described in Section 6.5.6.

The X-35C engine was delivered and installed in early August, during which time the aircraft was undergoing Ground Vibration Testing; these were completed in mid-August. The X-35C First Flight Readiness Review (FFRR) was also completed at this time. [124] Heat exchanger modifications were completed in mid-October; structural coupling testing and APU checks completed by the beginning of November.[125] Flight test software acceptance testing was completed and the software was installed to the aircraft on 6 December. Final maintenance and system test actions were completed in early December, clearing the way for taxi and flight tests, as discussed in Section 6.5.6. [126]

6.5.6 Lockheed CDA Flight Operations

The first taxi of the X-35A was conducted in mid-October 2000. First, ramp taxi and low speed taxi testing up to about 70 kt was completed. Low speed taxi tests identified an angle of attack (AoA) discrepancy between the noseboom and fuselage mounted probes. Lockheed Martin corrected the problem and validated the fix during a repeat of the taxi test on 19 October. The JSF Program Director approved flight clearance for the X-35A on 20 October. [127]

Figure 142. X-35A conducted taxi tests in mid-October 2000.[128]

X-35A CTOL successfully completed first flight on 24 October 2000, taking off at 9:06 a.m. Pacific Daylight Time from Palmdale (see Figure 143). The initial flight profile included check-outs of the on-board systems, handling characteristics and down-link connections for the constant stream of critical data-transfer to the flight-test technicians at Palmdale and Edwards Air Force Base. The X-35 climbed quickly to an altitude of 10,000 feet, maintained an airspeed of 250 knots while accomplishing a series of figure-eight maneuvers to demonstrate key handling qualities and to validate design predictions. [129]

Figure 143. X-35A makes its maiden flight from Palmdale on 24 October 2000. [130]

The 28 minute flight concluded with a successful landing at Edwards AFB. All planned test points, except those for gear retraction, were accomplished. Gear retraction test points were deferred due to anomaly in the main landing gear door closure noticed during initial gear cycling tests in flight. Post flight changes were made to resolve the gear door issues and additional ground gear swings were completed. [131]

After first flight, the X-35 quickly expanded the envelope and, over the next month, completed all of the key test objectives. The first Air Force test pilot to fly the X-35 was Lt. Col. (b)(6) on the fifth flight. He flew a series of maneuvers, including afterburner operation, designed to evaluate the airplane's basic handling characteristics. During the 36-minute flight, Smith reached an altitude of 10,000 ft and a

maximum speed of 360 kt. On 2 November 2000, Lockheed Martin test pilot [redacted] continued expansion of the X-35A's flight envelope to 390 kt at 10,000 ft with a series of increasingly aggressive maneuvers, including rolls, sideslips and afterburner transients. [132]

On 7 November 2000, the X-35A took on fuel from a KC-135 tanker for the first time, enabling the aircraft to complete its longest flight: 2 hours and 50 minutes. The first Marine to pilot the X-35A was Maj. [redacted] the flight on November 10 took place on the 225th anniversary of the Marine Corps' founding. On 18 November, to pilots from the UK flew the aircraft. BAE SYSTEMS test pilot [redacted] logged more than an hour of flight time in two separate flights that included aerial refueling, formation flying and climbs to 25,000 feet. Squadron Leader [redacted] flew the aircraft, executing formation flying and air-refueling at 23,000 feet. X-35A went supersonic on November 21 after 25 hours and 25 flights, achieving a speed of Mach 1.05. [133]

The X-35A CTOL program was completed on 22 November 2000 with all objectives achieved or exceeded. The X-35A achieved the following accomplishments:

- Total flights – 27
- Total flight hours – 27.4
- Mach Achieved – 1.05
- G Achieved – 5.0
- Altitude – 34,000 feet
- Angle of attack – 20 degrees

According to Lockheed Martin, the following unofficial records were also set for accomplishments within the first 30 days of a X-demonstrator flight test program:

- Most flights – 27
- Most flight hours – 27.4
- Most pilots checked out – 6
- Fewest canceled flights – 2
- Fewest canceled flights due to instrumentation – 0
- Fewest VMS software changes – 0
- Highest flight rate – 6.3 Flights per week
- Highest flights per week – 8
- Fewest days from initial taxi to first flight – 11
- Fewest days from 0 airspeed to 480 KCAS – 24
- Shortest time to 10 flight hours – 17 days
- Shortest time to 20 flight hours – 26 days

The X-32A (aircraft 301) made its last flight to Palmdale, where it immediately began conversion to the X-35B STOVL variant. The flight LiftFan 3D had just arrived at Pratt & Whitney for acceptance testing from Rolls Royce North America. [134]

The JSF Program Office issued a Flight Clearance Certification for the X-35C carrier variant in mid-December. The X-35C CV (aircraft 300) successfully completed low, medium, and high speed taxi tests this week with no major issues identified. At 9:23 a.m. PST on 16 December, test pilot [redacted] launched the X-35C from the Lockheed Martin Aeronautics plant in Palmdale, Calif., and flew the plane for 27 minutes before touching down at Edwards Air Force Base. The aircraft climbed to 10,000 feet and accelerated to 250 kt (288 mph). [redacted] cycled the landing gear and performed aircraft flying-qualities evaluations, including rolls, sideslips, and overall systems checks. Primary differences from the X-35A include a larger wing and control surfaces, the addition of ailerons and a special structure to absorb high-

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impact landings.[135] Two additional flights took place on 19 December in preparation for commencement of FCLP testing. [136]

Figure 144. X-35C descends for its first landing at Edwards EAFB. [137]

On January 31, the X-35C made its first supersonic flight, reaching Mach 1.10 (later it achieved Mach 1.15). On February 10 it flew 2,500 miles to Patuxent River, via Ft. Worth, Texas, becoming the first "X" plane in history to complete a transcontinental flight. Eight pilots have flown the aircraft. Flying up to six missions per day, the X-35C completed its flight-test program after achieving all objectives on March 10. The airplane logged a total of 73 flights and 58 hours in the air and completed 250 FCLPs (field carrier landing practices).[138]

The X-35B STOVL propulsion system hardware completed acceptance testing at Pratt & Whitney on 20 December. The system – including the shaft-driven Lift Fan (LF3D), SE611 engine, three-bearing swivel nozzle, and lateral roll-post ducts – was checked out in more than 20 hours of successful testing which included numerous clutch engagements. The hardware was shipped on 21 December and it was installed over the holidays. The Lift Fan was installed in the X-35B in less than three hours. A laser-alignment check verified that the fit was essentially perfect.[139]

Figure 145. Lift Fan installation converts aircraft 301 to the X-35B. [140]

The X-35B began hover pit testing in Palmdale in late-February. The test series included 26 Lift Fan clutch engagements from CTOL to STOVL mode at high engine RPM. The X-35B repeatedly operated at maximum STOVL thrust levels for periods of up to 90 seconds. Individual test series were regularly run with a full aircraft fuel load for as much as an hour. [141]

Figure 146. X-35B conducting hover pit testing at the Lockheed facility in Palmdale, California.[142]

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[115] Lockheed Martin, Press Release, "Joint Strike Fighter X-35A is Painted in Palmdale," June 9, 2000.
[116] JSF Weekly Activity Report, 4-10 March 2000.
[117] JSF Weekly Activity Report, 22-28 April 2000.
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[119] Lockheed Martin, Press Release, "Lockheed Martin X-35 JSF Successfully Completes Structural Loads Testing," June 23, 2000.

[120] Lockheed Martin, Press Release, "Lockheed Martin X-35 JSF Successfully Completes Structural Loads Testing," June 23, 2000.

[121] JSF Weekly Activity Report, 17-23 June 2000.
[122] JSF Weekly Activity Report, 5-11 August 2000.
[123] JSF Weekly Activity Report, 19-25 August 2000.
[124] JSF Weekly Activity Report, 12-18 August 2000.
[125] JSF Weekly Activity Report, 28 October – 3 November 2000.
[126] JSF Weekly Activity Report, 2-8 December 2000.
[127] JSF Weekly Activity Report, 14-20 October 2000.

[128] Lockheed Martin, Press Release, "Lockheed Martin X-35A JSF Completes Taxi Tests, Readies for First Flight," October 21, 2000.

[129] Lockheed Martin, Press Release, "Lockheed Martin Joint Strike Fighter Takes Flight," October 24, 2000.
[130] Lockheed Martin, Press Release, "Lockheed Martin Joint Strike Fighter Takes Flight," October 24, 2000.
[131] JSF Weekly Activity Report, 21-27 October 2000.
[132]Lockheed Martin, Press Release, "Air Force Flies Lockheed Martin X-35A JSF,Envelope Expansion Continues on Fifth Flight," November 6, 2000
[133]Lockheed Martin, Press Release, "Lockheed Martin JSF Goes Supersonic; Test Objectives Exceeded," November 22, 2000.
[134] JSF Weekly Activity Report, 25 November - 1 December 2000.
[135]Lockheed Martin, Press Release, "Navy Variant of Lockheed Martin JSF Takes Flight," December 16, 2000.
[136] JSF Weekly Activity Report, 16-22 December 2000.
[137] Navy Variant of Lockheed Martin JSF Takes Flight," December 16, 2000.
[138] Lockheed Martin, Press Release, "Lockheed Martin's Navy JSF Completes Historic Flight-Test Program," March 12, 2001.
[139] Lockheed Martin, Press Release, "Lift Fan Installed in X-35B Following Successful Tests of JSF STOVL Propulsion System," January 11, 2000
[140] Lockheed Martin, Press Release, "Lift Fan Installed in X-35B Following Successful Tests of JSF STOVL Propulsion System," January 11, 2000
[141] Lockheed Martin, Press Release, "Lockheed Martin JSF X-35B Begins Hover-Pit Testing," February 23, 2001.
[142] Lockheed Martin, Press Release, "Lockheed Martin JSF X-35B Begins Hover-Pit Testing," February 23, 2001.

7 JSF Field Activity Support

Significant activities of the JSF Program are conducted at the service field sites. Little mention of these field activities was made above partly because they are so well integrated into the responsibilities of the IPTs and Directorates. The JSF Program has, in effect, created a virtual, geographically dispersed, program office. Nonetheless, some discussion of the specific undertakings and accomplishments of the most involved JSF field sites will be covered in the following sections.

7.1 Wright-Patterson AFB

Wright-Patterson Air Force Base (WPAFB), Ohio is the foremost aeronautical research and development center in the Air Force and headquarters for the Air Force Materiel Command (AFMC). Primary JSF support comes from the Aeronautical Systems Center (ASC) and the Air Force Research Laboratory (AFRL), which includes what was previously known as Wright Laboratories (WL). From the earliest days of the JAST program, Wright Laboratories was involved in conducting Tech Mat research, as well as providing technical and other support to many JAST projects. As the JAST program has matured to become a full system program, the Tech Mat process has narrowed the topics being researched. AFRL has followed this same path and is currently concentrating its JSF technical maturation research and support on areas such as composite structures, next generation transparencies (canopies), low observable technologies, manufacturing technologies, next generation avionics and on-board electronics integration. Since CDP, with the transition away from Tech Mat, JSF has required less support from AFRL and more from ASC.

The JSF Support Office, ASC/FBJ, operates under the Air Combat SPO, ASC/FB. The mission of the JSF Support Office is to provide integrated AFMC support and resource management to the JSF Program Office through the IPT process. ASC/FBJ represents a single focal point for integrating AFMC-wide support to JSF. AFMC product centers, laboratories, test centers, and logistics centers are coordinated through this office.

7.1.1 Weapon Systems Support

The initial core of USAF support at WPAFB during the start-up and continuation of the JAST effort was comprised of personnel from the USAF Multi-Role Fighter (MRF) project. This project was being executed at ASC by a team of mostly technical resources (program managers, development engineers, analysts, logistics and technologists) representing functional disciplines that were considered important in defining the overall weapon system. The MRF team also had representation by operators from Air Combat Command (ACC).

As discussed in Chapter 2, the objective of the MRF program was to investigate relatively low-cost F-16 weapon system replacement options for the USAF. When MRF was canceled during the BUR, it was an obvious choice to re-direct the available resources from MRF toward the emerging JAST Program. This took advantage of the knowledge gained to date and applied the available expertise to laying out a foundation for the evolving JAST Program.

The initial ASC JAST transition team was lead by Lt Col (b)(6) [redacted] and manned by 20 personnel transferred from the MRF program. ASC Engineering (EN) provided additional engineering expertise. Since the ASC team would be more effective if its members were collocated, an Advanced Fighter Projects division (ASC/XRJ) was created within the Development Planning Directorate (ASC/XR). Facilities required/provided for the ASC team by ASC/XR consisted of normal office space for Support Team personnel, secure/special access vault space for modeling and simulation computer resources and activities, and classified/special access data storage and meeting space. While the JAST Support Team was resident in ASC/XR, this secure/special access vault facility was shared with other XR projects. During this time, ASC participated in compiling a current status of strike fighter developments to date, with particular

focus on those technologies deemed high payoff or critical to developing an affordable strike fighter weapon system.[1]

As the JAST Charter evolved, so did an AFMC/ASC charter for the XRJ team. Lt Col Forker initiated periodic reviews with the ASC and AFMC senior leadership to keep them apprised (and supportive) of the resources and efforts being dedicated to the JAST program. The key functional leadership (Engineering, Technology, Development, Acquisition, and Logistics) at ASC became known as the J-Council (J – for JAST). Following an initial review of the USAF efforts with the AFMC Commander (Gen Ronald Yates) in January 1994, quarterly reviews with the ASC J-Council were initiated.

As the JAST Program organization was defined, the JAST Support team at ASC provided counterparts to the JAST IPT leads. One decision at the first ASC J-Council review, in March 1994, was to identify co-leads to serve as these counterparts—one representing the development and acquisition function (primary) and one representing the technology function (alternate). This dual representation continued throughout the first phase of JAST.

USAF support to the JAST Program continued to receive high level attention. In preparation for the second J-Council review in June 1994, the ASC corporate body wanted to emphasize the importance of this support by formally reviewing and approving the resources dedicated to JAST. This was accomplished by an individual review of personnel qualifications for their assigned area under JAST. Each member, the primary and alternate, was presented to the J-Council for this review and approval. Lt Gen Fain concluded with a presentation of a formal set of Rules of Engagement for functioning on IPTs, and an official "Charge to the POCs."

During 1994, XRJ provided top-level status of S&T efforts supporting JAST objectives, conducted S&T reviews at many locations, initiated interfaces with the nearby F-22 SPO, to interchange on their current philosophy for Work Breakdown Structure (WBS) and specifications for the F-22 concept, and conducted interchanges with key ASC technology and acquisition experts to bring the most pertinent set of "best practices" to the JAST development efforts. XRJ also assisted with preparation for and source selection of the BAA 94-1 and 94-2 efforts.

During discussions in early 1994 with Mr. Ray Haas (SES, ASC/EN), technical director for the AFMC support, (b)(6) [redacted] and (b)(6) [redacted] emphasized the importance of establishing "proven" capability, i.e., a strong foundation for supporting the next generation of strike fighter weapons systems. Their discussions led to an agreement to tap key resources to develop the ground rules and guidelines that would be useful in evolving the approach and objectives for Tech Mat activities. Mr. Haas established a small JAST Ground/Flight Demonstration Focus Team from WL and ASC/EN to address advanced planning for Tech Mat that would support the objectives, direction and time-line originally defined for the JAST effort. Lessons learned were drawn from similar activities conducted during efforts such as the Lightweight Fighter (LWF) YF-16/YF-17 program, the X-29 Forward Swept Wing program, the Advanced Flight Technology Integration (AFTI) F-16, etc. A primary theme of this team was that the demonstrations must be the most cost-effective approaches, accounting for the broad, joint-service scope, the limited funding, and the given time frame. The rigor of any demonstration must satisfy minimum criteria that will verify or substantially prove the capability. An agreed-to hierarchy (from lowest to highest cost) was to first consider the use of modeling & simulation; then address ground-level component demonstrations; then to look at actual flight test efforts. The results from the efforts of this team helped in establishing guiding principles for the Technology IPTs to use in defining the development activities for critical technology demonstrations in their functional/product areas.

The organization and structure of the ASC JAST Support team has continued to parallel the organization and structure of the JSF Program Office in Crystal City, Arlington, VA. The mission and role of the ASC JAST Support team was to provide technical and management support as requested by the JSF Program Office Directorate and Integrated Product Team leaders and to act as the Program Office's conduit

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for support from other Air Force Material Command product centers, test centers, laboratories and other AFMC agencies.

When the JAST Program was officially designated as an ACAT 1D program as the Joint Strike Fighter in 1996, the ASC JAST Support Team was renamed the Joint Strike Fighter Support Office and moved from ASC/XR, Development Planning Directorate, to ASC/FB, the Air Command and Strike Mission Area Group. The JSF Support Office (ASC/FBJ) was established on 1 June 1996, with 26 people assigned. The mission and role of the office continued as before, but the level of support grew substantially in the transition from Tech Mat studies to full system program. Authorized manpower on the startup date was 43 positions: 17 Program Management/Security/Logistics, 21 Engineering, 1 Environmental, and 4 Financial Management. An additional 19 contractor support positions were authorized; the majority of these were funded by JSF/RQ to conduct M&S activities. ASC/FB provided office space for the current and projected authorized positions for the JSF Support Office. The office continued to share the vault facility with ASC/XR, executing a memorandum of agreement setting out roles and responsibilities between XR and FBJ.[2]

In 1995-96, ASC supported contractor technical reviews, drafted the Concept Assessment Team charter and developed a comparison package for YF-16/17, YF-22/23 & JAST. ASC also assisted in document preparations for the CDP source selection and participated on the CDP Source Selection Evaluation Team, with technical and cost personnel on site at the JSF Program Office for the duration. Cost team members and technical support were provided for development of the initial program EMD and unit recurring flyaway cost estimate as well as the commonality approach, rationale, and methodology.

The transition from CE through CDP Source Selection to execution of the Concept Demonstration Phase resulted in growth in the level of support requested from ASC/FBJ by the JSF Program Office. ASC/FBJ Support Office manning was projected at 61 authorizations through the fourth quarter of FY98: 20 Program Management/Security/Logistics, 35 Engineering, 1 Environmental and 5 Financial Management along with 22 contract support positions. In keeping with the competitive posture of the program, and Program Office policy on protection of proprietary information and physical security considerations, the ASC/FBJ Support Office space was configured to a controlled access area in October 1997.[3]

Air Force personnel continue to lead or serve as integral members of the JSF IPTs. Major accomplishments during 1997-98 include: converting the Joint Common Cost Model (JCCM) to a software format common to all JSF Program office sites and the contractors, developing the CAIV approach, rationale, and methodology, assisting with development of EMD phase model specification, developing initial JSF O&S cost estimate, and conducting several VSWE events at the ASC Simulation and Analysis Facility (SimAF). ASC also hosted the Man-in-the-Loop Air-to-Air System Performance Evaluation Model (MIL-AASPEM) conference and demonstration, and conducted a new System-of-System technologies "value to JSF" demonstration at the Air Force Research Lab.[4]

In 1999, major efforts included the development of the EMD Joint Model Specification and analysis of software schedule risk that led to the adoption of Block development approach for EMD planning; the mission systems cost estimating team received the Air Combat System Program Office team award for this effort. The JSF Simulation Team won an award for their outstanding achievement in modeling and simulation from the DoD's Modeling and Simulation office. WPAFB personnel also planned and executed the Requirement Directorate's participation in the Interservice/Industry Training Simulation and Education Conference (I/ITSEC 99) in Orlando, Florida, where they showcased the Strike Warfare Collaborative Environment (SWCE) and efforts focused at Simulation Based Acquisition (SBA).[5]

Activities during the year 2000 and early 2001 have been concerned with support of preparations for and execution of source selection activities. Current ASC/FBJ organization and manning is presented in Figure 147 below. Note that the structure of the Support Office duplicates the Directorate/IPT structure of

the JSF Program Office. Assigned personnel are listed under the Directorate/IPT they primarily support. Included are some of the personnel assigned out of the engineering "home office" (ASC/EN) to full-time support of JSF (not counted against the ASC/FBJ authorized positions). ASC/FBJ has recently been assigned dedicated vault space for the Special Access Program Facility for the JSF Support Office. However, Modeling and Simulation activities will remain in the Development Planning Directorate Secure/Special access vault facility.

Figure 147: ASC/FBJ JSF Support Office Organization (Dec 00)

7.1.2 Propulsion Systems Support

The propulsion support at ASC is separate from FBJ. There were initially four different Air Force organizations at WPAFB supporting the JAST/JSF propulsion development effort: ASC/LPJ was responsible for the (uninstalled) propulsion system, ASC/XRJ (the forerunner of FBJ) had propulsion engineers who were responsible for the aircraft performance with the propulsion system installed, ASC/ENFP was the technical/acquisition support home office, and engineers in several WL/POT divisions (lead by (b)(6) [redacted] in WL/POTA) was responsible for technology development for advanced programs. Although Wright Labs (now part of AFRL) figured prominently in early JAST Technology Maturation efforts, as the program transitioned to an engine development program, the effort likewise shifted to ASC/LP. There is still support by technologists at AFRL for propulsion and all technical areas of JSF development.

In early 1994, [redacted] the ASC/LPJ manager of the Engine Model Derivative Program (EMDP), began working as the Air Force JAST propulsion point of contact. The JAST engine technology studies task orders were added to the Pratt & Whitney, GE and Allison contracts (as described in Section 3.3.4).[6] [redacted] became the lead ASC JAST propulsion engineer in early 1995. By mid-1995, the JAST propulsion effort in LP had grown to about five people, and received its own designation, LPJJ. By early 1996, LPJJ had responsibility for leading the JAST propulsion effort for the Air Force. Later that year, they had grown to about a dozen people and received a "3-letter" designation, LPZ.[7]

In September 1997, the ASC Engine IPT (ASC/YFZ) of the F-22 System Program Office (SPO) co-located with the ASC JSF Propulsion SPO (ASC/LPZ) and was designated ASC/LPR. This move was conducted to better facilitate communications and manpower sharing for the management of the F119 engine family. As of the end of 1998, the combined LPZ / LPR divisions totaled nearly 50 people supporting the F119 family of engines, evenly split between JSF and F-22. Additionally, about twenty percent of the F-22/F119 engineers also spent some portion of their time assisting the JSF development.[8] Although XRJ/FBJ gave up its propulsion support role in 1996, Lt Col [redacted], the LPZ co-lead with [redacted] also serves as the interface with FBJ.

In 1999, the JSF propulsion support was reduced nearly 25% to streamline operations and reduce overhead in preparation for entry into EMD. Nonetheless, the LPZ team was nominated for the Air Force Association's Theodore Von Karman Award for spearheading the management of the development, assembly and initial testing on eight different developmental propulsion systems (CTOL/CV and STOVL for CDA and EMD for each WSC). This is award is "For the most outstanding contribution to national defense by either a military member or Department of the Air Force civilian, unit or group of individuals in the field of science and engineering, preferably relating to aerospace activity.[9]

7.2 NAWCAD Patuxent River

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, Maryland (see Figure 148) is the Navy's research, development, test and evaluation (RDT&E), engineering, and fleet support center for air platforms. It is home to the Naval Air Systems Command (NAVAIR). The Strike Aircraft Test Squadron (formerly the Strike Aircraft Test Directorate) drew down from the AFX program in late 1993/early 1994. At that time, approximately 12 people shifted over to partially support the JAST Program. The JSF program has since grown to 350 government and contractor personnel.

Figure 148: Aerial View of NAWCAD/Pax River

Initial support was in the area of source selection, with (b)(6) [redacted] of the Information Management Directorate developing and supporting the electronic source selection software. In 1995, personnel from the Technical Information Directorate and the Carrier Suitability Department of the Strike Aircraft Test Directorate produced a 45 minute long video entitled "The Navy Carrier Environment: A JAST Design Challenge." This extremely valuable production was developed to educate people about the unique carrier environment and the necessary design considerations to make a shipboard compatible aircraft. It was widely distributed among the JAST government and industry organizations. It was nominated for and eventually won a Cable Ace Award.[10]

Patuxent River's ACETEF facility hosted the original "Force Process Team" which developed the Strategy-to-Task matrix as described in Section 3.2.3 as well as most of the FPT wargames. NAWCAD Pax also hosted "VIP Day" with (b)(6) [redacted] and "Industry Day," where the Manned Flight Simulator (MFS) personnel performed human factors evaluations of prototype cockpit avionics configurations and symbology layout.

As described in Section 5.1.10, NAWCAD will be the test site for half of the JSF CDP involving two CDA from Boeing and two from Lockheed Martin. NAWCAD personnel hold key positions in the JSF program as IPT leads ((b)(6) [redacted] Systems Test; (b)(6) [redacted] Airframe; (b)(6) [redacted] Survivability) and leadership roles in Tech Mat programs. Since the early involvement in the JAST/JSF Program, support has grown to representation on nearly all of the IPTs and Directorates.

7.2.1 ACETEF

The Naval Aviation Systems Team Air Combat Environment Test and Evaluation Facility (ACETEF) is a fully integrated ground test facility allowing full-spectrum test and evaluation of aircraft and aircraft systems in a secure and controlled engineering environment. The facility uses state-of-the-art simulation and stimulation techniques to provide test scenarios that will reproduce actual combat conditions. ACETEF applies warfare environment and rapid display prototyping modeling and simulation to installed systems testing, hardware in the loop testing, and integration testing.

ACETEF's JAST/JSF work from 1994 through the end of 1996 was focused on two general areas supporting the FPTs. First, ACETEF (and NAVAIR 4.10) supported the Program's campaign-level war games (described in Section 4.2.4). Second, ACETEF began preparations to lead the Program's transition

from campaign-level war games through mission-level simulations (described in Section 5.2.5), and on to the engagement-level warfighting experiments using the Virtual Strike Warfare Environment (VSWE). ACETEF hosted four of the first six campaign-level FPTs and both of the mission-planning FPTs; off-site FPTs were also supported with Pax River modelers, analysts and warfighters.[11]

Figure 149: ACETEF Mission Simulation Displays

As previously discussed, the JSF campaign-level wargames were conducted at a rate of about two per year. Each campaign-level war game was preceded by six months of preparatory meetings to bring representatives of the various FPT organizations together. Then a group of about 50 people, mostly from the wargame host site and the JPO, plus small contingents from the other JSF organizations would gather at the host site to rehearse the event. The next week, between 100 and 150 people would assemble to conduct the game itself. The campaign-level wargames provided data, which helped the JPO refine the JIRD. Just as important, however, was the fact that the Generic JSF campaign-level games also provided enough information on likely JSF force allocations and mission assignments (at the theater-level) to permit JSF warfighting experiments to begin mission-level simulations. Both of these events were conducted at ACETEF, using ACETEF computers, scenarios and the SWEG model.[12]

ACETEF conducted the first Virtual Strike Warfare Environment warfighting experiment (VSWE 1) in May 1998, placing two pilots in simulated JSF cockpits and permitting them to fly a variety of strike and interdiction missions against a peer adversary using systems projected for 2010. ACETEF has subsequently conducted two further VSWEs (VSWE 5 in April 1999 and VSWE 6 in August 1999), each progressively more complex and achieving higher levels of fidelity in simulating JSF capabilities, the supporting and opposing systems, and C4ISR architectures that the aircraft is likely to encounter in 2010. VSWE 6 was a distributed event in conjunction with Joint Expeditionary Force Experiment 99 (JEFX 99) combining virtual JSF aircraft with live units in the Western Open Air Ranges. In addition to hosting VSWEs 1, 5 and 6, ACETEF also supported VSWEs 2, 3 and 4 with substantial technical expertise.

ACETEF's software engineering expertise has provided development support and testing for the Joint Interim Mission Model (JIMM), the model used for VSWE 6 and VSWE 7. In support of VSWE 7, ACETEF developed an Echo Range based scenario. VSWE 7 used the Defense Research Engineering Network to link ACETEF, Edwards AFB and Wright-Patterson AFB in JSF's first real-time High Level Architecture (HLA) virtual event. Integrated models for VSWE 7 included the JIMM, the Digital Integrated Air Defense System (DIADS), Missile Defense Space Tool (MDST), Extended Air Defense Simulation (EADSIM) and integration of ACETEF's Threat Air Defense Lab (TADL).

Although there was still work to be done, VSWE 7 successfully implemented the Strike Warfare Collaborative Environment (SWCE). VSWE 7 was the first implementation of the JSF Program Office's approach to Simulation Based Acquisition (SBA) that is evolving the virtual environment from CDP to

EMD. It will enable future collaboration between government and industry. It did so using six High Level Architecture (HLA) federates distributed over three geographically separate sites. It included additional models and hardware-in-the-loop via JIMM shared memory. It used both virtual and constructive components, and provided extensive database correlation. [13]

The SWCE will continue to develop through the addition of more C4I assets and communications architecture, and the addition of the red and blue air-to-air mission. It will expand to address the needs of system design, training, developmental testing and operational testing. VSWE 7 was a demonstration of the aggressive implementation of SBA by the JSF Program Office. [14]

7.2.2 Flight Test Facilities Preparation

NAWCAD is the test site for portions of the JSF CDP. NAWCAD provided support to the Combined Test Working Group (CTWG) and set up the JSF Joint Test Force (JTF) along with AFFTC and provided four test pilots and additional flight test engineers to staff the JTF Program.[15]

Lockheed-Martin's X-35 occupies the water side of Hangar 201, while Boeing's X-32 occupies Hangar 2133 (called "Hazelrigg"), each shown in Figure 150. Additionally, Pratt & Whitney has shop floor space on the road side bay of Hangar 201. Each contractor also has a relocatable office space (i.e., trailer) to house their staff, in all—hundreds of contractor personnel will work on-site during flight testing.

Figure 150: Hangars 201 and 2133 Used by the WSC Teams

NAWCAD operates three special facilities for the JSF STOVL test program: the graded hover pit, a ski jump to simulate a UK carrier, and a dedicated STOVL landing pad. The hover pit design was completed in 1998 and a contract was awarded in late September 1998. Construction began in December 1998. Progress on the Hover Pit as of mid-1999 can be seen in Figure 151. The curved vanes of the hover pit deflect hot engine exhaust away from the aircraft in order to simulate out-of-ground effect hover conditions. The Hover Pit was essentially complete in mid-November 1999.

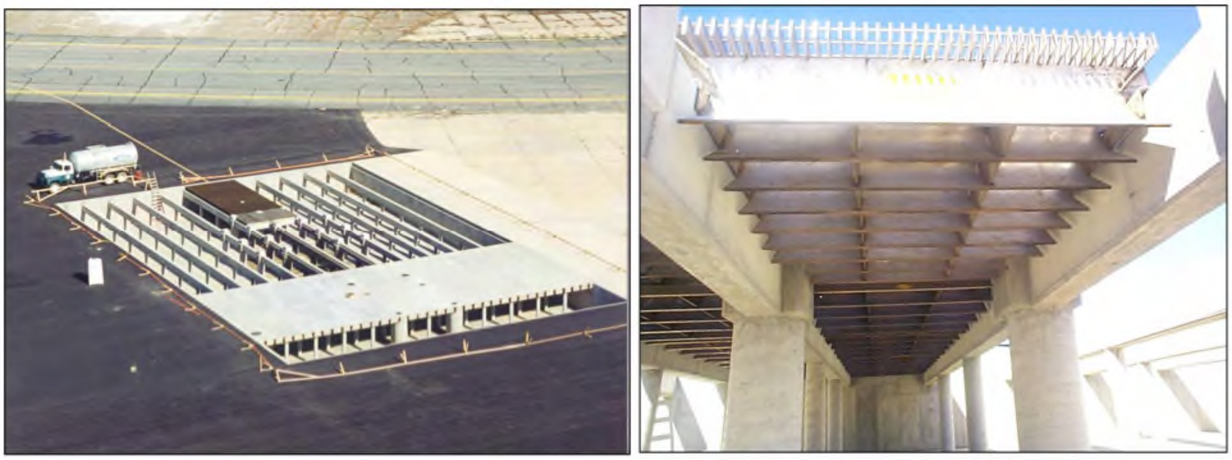

Figure 151: Progress on the Hover Pit as of mid-1999

Figure 152: Completed Hover Pit in November 1999

The ski jump ramp, located on the approach side of runway 20, was a modification of the existing ski jump ramp from the AV-8B program (Figure 153). Williams Fairey Engineering, in the UK, designed, performed structural analysis, and fabricated the necessary structural members to modify the existing ramp. A STOVL landing pad with AM-2 expeditionary airfield matting from a preexisting AV-8B facility at NAWCAD, Patuxent River, will also be utilized by the JSF Program.

Figure 153: Existing Ski-Jump Ramp Used for the AV-8B Program

As discussed in Section 6.5.6, the Lockheed Martin X-35C touched down at the Patuxent River Naval Air Station on 10 February 2001. Test pilot [redacted] a former Navy pilot, flew the X-35C on its first leg from Edwards Air Force Base to Fort Worth, TX. Following an overnight stay, U.S. Marine Corps [redacted] then flew the aircraft from Fort Worth to Patuxent River NAS.

On Saturday 10 March, Lockheed Martin successfully completed their X-35C Testing at Patuxent River. By all measures, the testing was an outstanding success for Lockheed Martin and the entire JSF Program. The X-35C flew 33 sorties in 28 days while at Pax. 250 Field Carrier Landing Practice test points were completed including both nominal and intentional off-nominal starts with superb results. The aircraft was flown supersonically to 1.15 Mach in the Off Shore Warning Areas. Four pilots (two contractor and two Pax River) shared in the duty of flying the aircraft. The Pax River pilots were LCDR [redacted] and [redacted], both assigned to Patuxent River NAS.[16]

Figure 154: X-35C Flying Over NAWCAD/Pax River.

From 9 February to 9 March 2001, the Patuxent River NAS hosted over 600 total visitors! This included one Senator, one Congressman, 26 Flag and General Officers, 4 SES level or flag equivalent DoD and foreign visitors, 313 DoD (Military and Civilian), 36 foreign visitors, 58 contractor visitors, 103 Civilian Guests, 25 Media Representatives, and 42 Congressional Staff personnel. The base also hosted another 250 JSFPO personnel and their families on Family Day. The support of this high visibility effort by the Pax River Team was unparalleled in terms of excellent cooperation, outstanding responsiveness, and a super Navy can-do attitude![17]

7.3 Air Force Flight Test Center, Edwards AFB

The Air Force Material Command's Air Force Flight Test Center (AFFTC) at Edwards AFB, California, is the nation's most extensive flight test facility. Located on 300,000 acres in the Mojave Desert, this historic base has been the scene of more major milestones in flight than any other place on earth. The AFFTC carries out flight test and evaluation programs for Air Force units, the Department of Defense, NASA and other governmental agencies. AFFTC also manages the Utah Test and Training Range where remotely piloted research and test vehicles, plus air-and surface-launched missiles, are tested and developed.

The AFFTC JSF Test and Evaluation (T&E) Support Office is a staff office under the 412 Test Wing Operation Group. The office was officially stood up as an Air Force activity on 1 October 1998, as 412 OG/OGX. The Office is the Commander, 412 TW and AFFTC lead for program management, advanced planning, program control, support resource requirements definition/development, direction and coordination for all AF JSF T&E support activities. The office assists the JSF Program Director and senior office staff in establishing the scope and content of JSF T&E, testing locations, resource requirements and T&E program execution. The office organizational structure is shown in Figure 155.

(b)(6)

[redacted]

Figure 155: Air Force T&E Support Office Structure

The AFFTC became involved with the JAST Program in May 1995, through an initiative briefing provided by Maj. General Richard L. Engel, Commander AFFTC, to the then JAST Program Director, Maj. General George Muellner. As a result of the briefing, the JAST program manager invited the AFFTC to

become a key activity in support of JAST DT&E planning activities. [redacted] was appointed as the AFMC and AFFTC lead for providing JAST T&E support. [redacted] started participating in JAST T&E planning beginning in June 1995, working with his USN counterpart from NAWC-AD, [redacted] was aligned directly under the Commander, 412 TW, and was a staff of one from June 1995 through January 1997.[18]

[redacted] participated in writing the JAST/JSF CDP statement of work in 1996 and was the Joint DoD-UK team lead for CDP source selection for ground and flight test. Additional JSF-dedicated staff members were assigned to the Commander, 412 TW, in 1997-98 to support JSF Program support needs, growing to a staff of 20 by the end of 1998.

In FY98, the T&E Support Office initiated site activation in support of planned flight testing of the Boeing X-32 and Lockheed Martin X-35 in 2000. Building 1820 (Figure 156) is being activated (i.e., modified*) to accommodate the X-35 and X-32 test teams as well as government personnel. Overall, the contractor and government DT&E personnel will be under the auspices of the JSF Joint Test Force, which will be led by Lt Col Paul Smith, USAF, and CDR Phillip Yates, USN. By the time flight testing begins in 2000, the T&E Support Office is expected to grow to 25 equivalent full-time positions.[19]

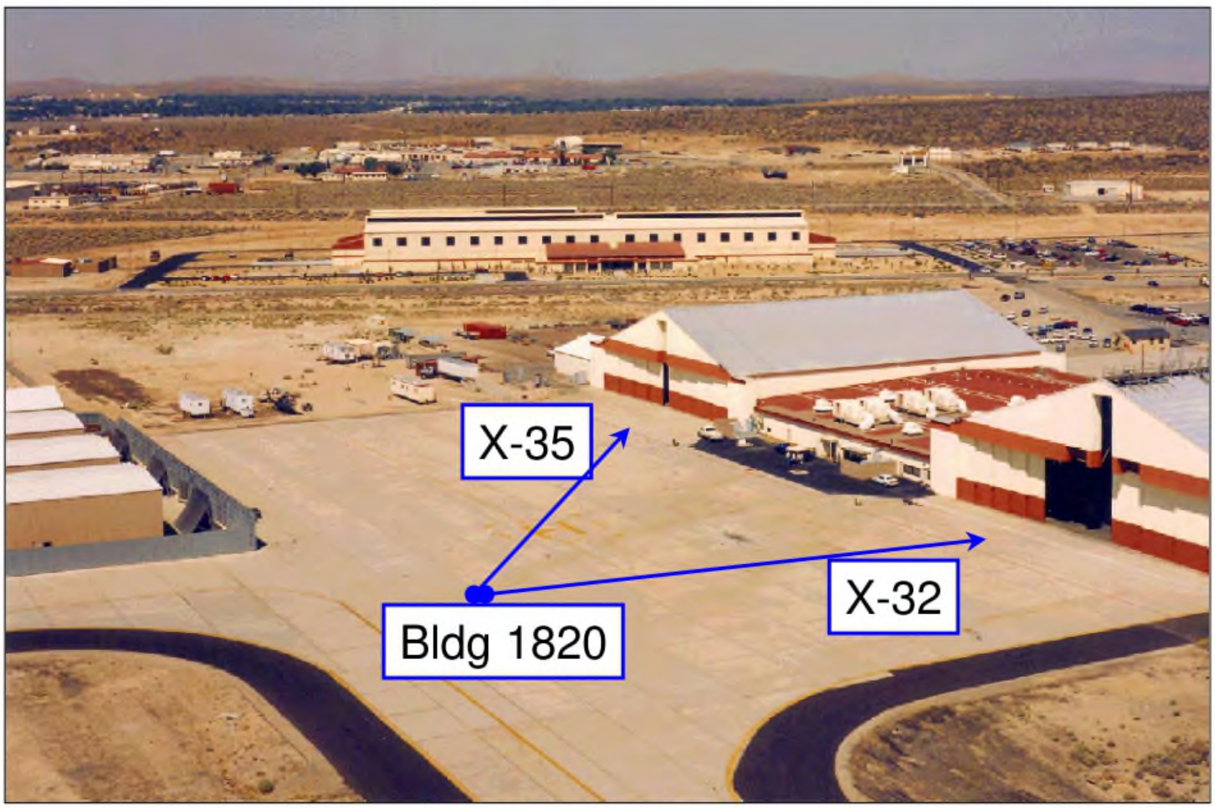

Figure 156: JSF JTF Facility, Edwards AFB, CA

AFFTC has officially recognized the JSF T&E Support Office as the lead test activity representing the JSFPO. As such, a signpost was erected in January 1999, officially designating Building 1820 and associated aircraft ramps and taxi areas as JSF operations areas. Building 1820 major modifications were completed in 1999 to accommodate contractor and government personnel. Additionally, computer and communications support systems, flight vision and Ops on-line were installed and facilities primarily ready

* In the early 1970's the Rogers Dry Lakebed side hangar (east hangar) was home to the XB-70 flight test program.

to support flight test. Building 3800, the Pratt & Whitney support facility, was also completed in October 1999 and is ready for occupancy. AFFTC range capability preparation is 90% complete for X-32 and X-35 flight test support in 2000. Overall, the Edwards site complex is 95% ready to support the CDA flight test program.[20]

7.4 NAWCWD

The Naval Air Warfare Center (NAWCWD), with major sites at located at Point Mugu and China Lake, California, is the Navy's primary weapons system research and testing facility. NAWCWD carries out the complete weapons systems development process, from basic and applied research through prototype hardware fabrication, test and evaluation, documentation, and fleet and production support. NAWCWD encompasses millions of acres of land and sea ranges which lie under thousands of square miles of joint service restricted land and sea airspace.

NAWCWD analysis and T&E capabilities include simulation of threat weapons systems; major electronic-warfare threat-simulation facilities; and complete test and evaluation—static, live fire, captive carry, supersonic track, environmental, radar cross section—of a wide range of antiair and antisurface systems. Contributing to and complementing these projects are broad technology-based efforts, which range from basic research in physics and chemistry to applied projects in energetic materials, embedded computers, specialized semiconductor and superconductor materials, and lasers and optics. NAWCWD also has major system and software aircraft integration and test capabilities for the F/A-18, F-14, EA-6B, AV-8B, AH-1 and EP-3 platforms. These support activities provide analysis, development, acquisition, DT/OT, and fleet introduction services through their NAVAIR sponsors, with a focus on post-production support through end of service life.

Directed by [redacted] the JAST/JSF efforts at NAWCWD began in 1994 as a follow-on to efforts from previous advanced aircraft programs (A-12, NATF and A/F-X). Early NAWCWD JAST efforts included the execution of BAAs, which identified and applied innovative and creative ideas for critical/enabling technologies with respect to weapon delivery concepts. [redacted] led the NAWCWD efforts until the spring of 1998. [redacted] followed [redacted] in July of 1998. The level of effort and expertise NAWCWD provided has varied during each of the phases of JSF. At the end of 1998, NAWCWD had approximately 24 man-year equivalents spread across a multitude of engineering and scientific disciplines working on the JSF program (as shown in Figure 157).

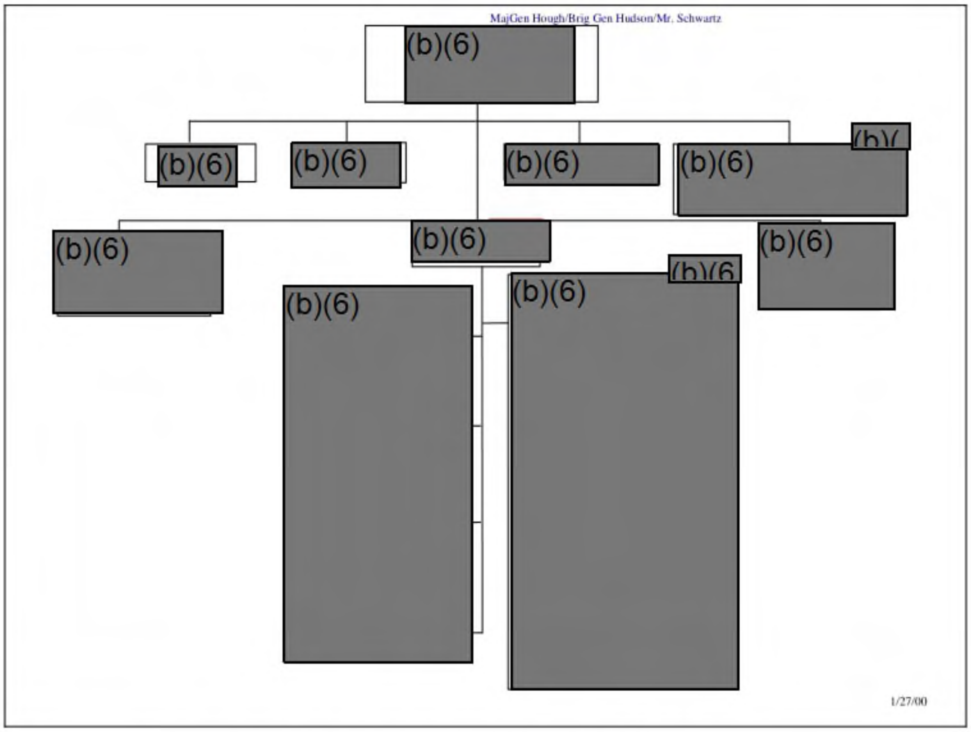

Figure 157: NAWCWD Organization (Jan 00)

NAWCWD, led by [redacted] has supported JSF Requirements generation since 1995 by developing Design of Experiments (DOE) to support various studies, such as VSWE and COPT; NAWCWD's contributions have made a profound impact on the direction the requirements analysis community in JSF has gone. NAWCWD personnel have supported the Modeling, Simulation and Analysis tasking by performing model Validation, Verification and Accreditation/Certification (V, V, A/C) for the JSF Program. NAWCWD engineers have also provided valuable input to the releases of JIRD, and supports the transition of the JIRD into the JORD, and its engineering-level successor, the JSF Model Specification (JMS) with critical expertise in weapons integration, computer resources, and mission planning.

The NAWCWD Mission Systems IPT members have been led by [redacted] since 1995. Key areas have been in software technology, integrated core processing, weapons integration and lethality, mission planning, SoS, PHM and avionics cost estimation. NAWCWD has also contributed in JSF survivability and vulnerability efforts, including live fire test planning, electronic warfare effectiveness of countermeasure systems, as well as providing electronic defense systems and countermeasures expertise. Additionally, NAWCWD has provided expertise in the supportability of suspension equipment and stores loading, system security engineering, laser eye safety, pilot vehicle interface (PVI), crew systems, EO/IR sensors and gun systems.

Several technology demonstrations for JAST/JSF have occurred at NAWCWD. NAWCWD JSF and AV-8B personnel led the Integrated Helmet Audio Visual System (IHAVS) demonstration in FY95-96. As discussed in Section 4.3.1, this project resulted in the successful integration of several leading-edge PVI technologies into an existing test-bed aircraft: off-boresight acquisition, and the use of audio cues and voice commands with a helmet-mounted display.

~~FOR OFFICIAL USE ONLY~~

Figure 158: AV-8B Used in IHAVS Testing

Another demonstration was the Open System Ada Technology (OSAT) project. The OSAT program was aimed at reducing the risk of integrating new technology by using COTS processing and a commercial software development environment and operating system that supported multiple high-order languages. The NAWCWD TAV-8B was used to host the COTS processing equipment, developed by then-MDA; NAWCWD personnel and facilities were also used to manage the acquisition, provide engineering guidance and requirements control, and provide laboratory integration testing before flight tests. The aircraft successfully flew to different flight profiles and delivered six practice bombs within expected accuracy on NAWCWD test ranges, using a NAWCWD-heritage algorithm for the bombing algorithm re-coded in Ada.

FY 99 NAWCWD JSF support included participation in ORD refinement, JMS modifications, evolutionary EMD block planning, government/contractor reconciliation activities and EMD activity planning. As described in Section 5.2.5, a JSF Imagery for Lethality (JIFL) demonstration event was also conducted at NAWCWD in February 1999. The demonstration clearly illustrated to the aircrew the value of the pilot having multiple sources of target and target area imagery directly available in the cockpit (see Figure 159) during different missions and at different levels of fidelity and timeliness.

Figure 159: JIFL Demonstration Displays

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[1] Schwenke, RB and Terry Dudley, comments provided to the authors, 5 February 1999.

[2] *Ibid.*
[3] *Ibid.*
[4] *Ibid.*
[5] [redacted] RB comments provided to the authors, 8 January 2000.
[6] [redacted] interview with the authors, 26 January 1999.
[7] [redacted] interview with the authors, 27 January 1999.
[8] *Ibid.*
[9] [redacted] Lt Col, USAF, interview with the authors, 19 January 2000.
[10] Comments provided by [redacted] February 1999.
[11] Comments provided by [redacted] February 1999.
[12] *Ibid.*
[13] [redacted] "VSWE 7 Final Report," draft, March 2001.
[14] [redacted] "VSWE 7 Final Report," draft, March 2001.
[15] Interview with [redacted] January 1999.
[16] Comments provided by [redacted] March 2001.
[17] Ibid.
[18] [redacted] comments provided to the authors, December 1998.
[19] *Ibid.*
[20] [redacted] comments provided to the authors, 10 December 1999.

8 Acquisition Reform and Streamlining

Since its inception, the JSF Program has been the acknowledged leader in the implementation of DoD acquisition reform and pioneered many acquisition reform concepts. The program office also continuously applies lessons learned to improve both its own processes, and to communicate those lessons to the rest of the DoD acquisition community for the benefit of other programs.

As stated in the original JAST Charter, "Across the spectrum of JAST [subsequently JSF] Program efforts, the Director will seek out and apply streamlined and innovative practices." The JSF Program has fulfilled this charter, as evidenced by the following awards recognizing excellence in DoD acquisition reform and streamlining:

Navy Procurement Competition Award, June 1995. Presented by (b)(6) [redacted], Secretary of the Navy, to several members of the JAST Program Team for the JAST Broad Agency Announcement (BAA) 94-1 and 94-2 electronic source selection efforts.

Endorsement by President Clinton, August 1995: "This good inter-service cooperation has to be the wave of the future."

DoD Joint Meritorious Unit Award, April 1996 (for performance from January 1994 through June 1995): "For progressing at an incredible rate to establish a secure foundation for the successful development and production of next-generation strike weapon systems for the services and allies." (The full citation appears in Appendix B of this document.)

USAF Acquisition Lightning Bolt Award, March 1997: "For outstanding contribution and diligence in developing and implementing innovative processes and practices." (Full citation in Appendix B.)

DoD David Packard Excellence in Acquisition Award, March 1997: "For acquisition excellence and superior performance as DoD's flagship innovative family of aircraft program"—reducing development, production, and ownership costs. (Full citation in Appendix B.)

8.1 Organization and Staffing

8.1.1 Joint Program Structure

One of the most important features of the JSF Program organization is the extent to which it is a truly *joint* program. The program has achieved an unprecedented level of cooperation among the participating services, and between the operational and development communities. This cooperation is the result of careful planning—as set forth in the original JAST Charter—to establish proper checks and balances, and to insure that relevant interests are adequately represented within the program office on a continuous basis.

No single executive service. The JSF Program Directorship rotates every two to three years between the Department of the Air Force and the Department of the Navy. The Program Director is a two-star flag officer (O-8) from one Department, and the Deputy Program Director a one-star (O-7) from the other Department. The Program Director reports through the SAE of the *opposite* department, to the USD(AT&L), who is the Milestone Decision Authority (MDA).

By reporting directly to the applicable SAE, rather than through a Program Executive Officer (PEO), the JSF reporting path is one step shorter than in most acquisition programs.* (Actually, the JSF Program

* In major programs, the Program Director normally reports to a PEO, a flag officer who is responsible for all of that services' programs in a specific area, e.g. tactical aviation. The PEO then reports to the SAE, who in turn reports to the MDA. In the case of ACAT I C programs (major programs involving one Component), the MDA is normally the service (Component) head. For ACAT I D programs (major programs for which DoD has oversight) the MDA is the USD(A&T). The 1985-6 Packard Commission established this four-level structure, but also noted that the path could be shorter in specific cases. Accordingly, Certain high-priority programs use an abbreviated reporting path, in which the Program Director reports directly to the SAE. In

Director *is* essentially, a PEO.) This arrangement has fostered a valuable, close relationship among the JSF Program and the acquisition leadership of the services and DoD. Lines of authority also cross service boundaries at each level. When the Directorship rotates, the service "losing" the Program Director position thereby gains program oversight at the SAE level, and also assigns the new Deputy Director. This provides both balance and continuity for the long term.

Having a flag officer from each participating military department within the JSF Program Office represents the highest level of integration at which the services are working on the JSF. In other words, while each service has a number of its organizations performing various support functions for the JSF Program, those organizations are not co-located and do not work together on a day-to-day basis. If such necessary interaction is to occur, it must occur in the JSF Program Office. In this way, any statement or position issued from the JSF Program Office has, at least implicitly, the endorsement of a flag officer from each Department and each Department may be confident that its interests are adequately represented. Conversely, there are numerous personnel in the JSF Program Office who can represent program issues back to their respective services, and to raise any issues requiring a constructive resolution.

The rotating SAE arrangement in practice requires that the SAEs of both Departments be kept "in the loop" on JSF Program matters, since one is, and the other will be, in the JSF Program Director's formal reporting path. (For example, both SAEs signed the JSF SAMP during the Milestone I review process.) This adds to the Program Director's briefing responsibilities, but pays off in the long run by providing balance and continuity, and effectively creating a situation in which *"both services are absolutely convinced they own this program,"* according to Lt Gen George K. Muellner (the first JAST Program Director, who was later the Principal Deputy to the Air Force SAE).[1, 2]

Funding is provided equally by the Departments of the Air Force and the Navy; however, separate Air Force and Navy funding lines are maintained, rather than having all the money in a single "purple pot." While adding some administrative burden, this arrangement further contributes to a sense of joint ownership, and helps prevent unilateral changes to program funding.[3] Within the JSF Program Office, responsibility is well balanced. Most Directorates and IPTs within the JSF Program Office have a director or lead from one service, a deputy from the other, and a balanced membership at the working level. All JSF Program Office personnel are fully integrated into its actual work and are assigned program management duties, not just liaison roles. This level of involvement fosters a sense of teamwork and common goals.

Because the JSF Program is avoiding the "TFX Syndrome" of forcing a single weapons system to do everything, the JSF originated "Family of Aircraft" concept recognizes the need for certain service-unique characteristics, and responds to the acknowledged need for a variant for each service. The level of commonality among variants is being determined by a rational decision process that takes into account affordability and not dictated by arbitrary percentage levels. The importance of each service-unique requirement must be weighed against the cost of meeting it and the opportunity of meeting the requirement in some other way.

All of these factors are helping the JSF to overcome the difficulties traditionally encountered in past joint-service acquisition programs. Critics especially like to point to the Tactical Fighter, Experimental (TFX) Program in the 1960s that led to the F-111. In this Air Force-led program, the Navy was essentially forced to accept a large, heavy aircraft determined by Air Force long-range interdiction requirements. The Navy's version (i.e., the F-111B) was, predictably, unsuitable for carrier operations, and the Fleet air defense role. The Navy ultimately dropped out of the program. Historically, the greatest problems in the TFX and other multi-service programs have been:

- Failure to reconcile conflicting operational requirements

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the Navy, these are referred to as Direct Reporting Program Managers (DRPMs). The A/F-X Program, which was canceled when JAST was initiated, was a DRPM program.

- Cost growth
- Frustration, and ultimately withdrawal of support, on the part of the non-lead service(s)

In the JSF Program, there is no non-lead service and no service's requirements are more important than any other services requirements. The participating services share all aspects of program management responsibility and funding, and are working together to develop affordable, realistic requirements where each service's "must have" requirements are met. (Acquisition reform initiatives in the area of requirements are discussed further in Section 8.4).

8.1.2 Warfighters and Technologists Together

The JSF Program Office staff includes not only development and acquisition personnel, but also operators and maintainers from all participating services. This provides an opportunity for two key types of interaction: 1) developer input into the requirements process, and 2) warfighter/maintainer input into technology investment decisions and the evolution of weapons system concepts.

This was a key recommendation of the 1986 Packard Commission report, and represents a departure from the "traditional" process, in which operators write the requirements documents and, in the worst case, "threw it over the fence" to the acquisition community for implementation. An acquisition program office then assumed responsibility for developing a system that met the "carved in stone" requirements—whatever the cost. The operators often had little further involvement in the process, until it was time for operational test & evaluation (OT&E) of production representative systems. Several acquisition reform panels over the last 25 years recognized the need for greater developer input to the requirements process, and greater user involvement in the development process. The JAST/JSF staffing concept accomplishes this by putting the users and the developers together from the very beginning.

8.1.3 Not (Initially) an Acquisition Program

JAST was originally chartered as a non-Acquisition Category (ACAT) program for two main reasons. First, it was very specifically intended that the program should not prematurely focus on the development of any specific weapons system(s), but rather should allow such acquisition decisions to fall out naturally from the interaction between the service requirements and the technology communities. The second reason was to facilitate the implementation of streamlined and innovative processes. However, this did not mean avoiding proper controls or checks and balances. The JAST Program Director's reporting channels were similar to those of a major, high-visibility acquisition program. The program was still reviewed at the same levels and by many of the same groups reviewing an ACAT I D program. A notable example is the extensive series of reviews conducted during the latter half of 1995 to obtain the approval and endorsement of the JROC, the DAB, and participating services' senior leadership before proceeding with the Concept Demonstration Phase solicitation. The non-ACAT status simply meant that the JAST Program Director could, with the understanding and agreement of service and DoD acquisition principals, deviate from "normal" acquisition policies and procedures in ways that would facilitate the accomplishment of the program's charter, provide significant cost savings, and/or lead the way in demonstrating new processes that may eventually be incorporated into the mainstream acquisition system.

As a result, when JAST became JSF and was designated an ACAT I D acquisition program in early 1996, no significant changes in program management were required. The program was already reporting through the same channels as an ACAT I D program. The necessary Milestone I reviews had, in substance, already been accomplished, and all that remained was to transfer the results of those reviews into the appropriate formal documentation. Additionally, by that time DoDD 5000.1 and 5000.2 had been changed to encourage tailoring of programs along the lines of the JAST/JSF model.

8.1.4 Advisory Group & Executive Committee, and Reduced Pre-Briefings

The JAST Charter called for an Advisory Group and an Executive Committee to support and advise the Program Director, the SAEs, and the USD(A&T), on JAST Program matters:

> The services will support a two-star level (or equivalent) Advisory Group to act as a sounding board and support forum for the JAST Program Director and the service Acquisition Executives (SAEs). Additionally, an Executive Committee chaired by USD(A&T) will be supported by the services to act as an advisory body to the USD(A&T) on the JAST Program….
>
> The JAST Program Director will not be required to pre-brief or coordinate through the multitude of supporting staffs of the members of the Advisory Group and EXCOM [Executive Committee]. Similarly, briefings will be presented to the Advisory Group and EXCOM as a group… Informal meetings with the SAEs and USD(A&T) are encouraged.[4]

The intent to reduce the pre-briefing burden on the JAST/JSF Program Director has met with mixed success. In some cases the Director and/or Deputy Director have been able to go directly to acquisition principals on program matters, particularly those who had been directly involved in starting the program. However, this has become more and more difficult over time. Many of the original acquisition officials who were intimately familiar with the program have retired or moved on to different assignments. JSF still maintains a close relationship with the SAEs and with USD(AT&L). However, as the program has grown, it has become necessary to maintain relationships with a growing number of outside agencies.[5]

8.2 Business Practices

The JSF Program has implemented many initiatives to streamline its business operations, and to facilitate the development and procurement of the best possible products at the lowest possible cost. JSF executes a broad range of contracting activities, ranging from exploratory studies and research & development, through the major CDP weapons system and propulsion contracts awarded in 1996. Some of the initiatives discussed below apply primarily to the smaller-scale contracts, while others are specific to the CDP contracts, and others relate to internal program office operations. It is important to remember that the processes used for the CDP source selection and contract execution did not appear overnight, but are the product of a continuous effort since the beginning of the program.

8.2.1 Acquisition Reform Focus Team

Within the first year of the JAST Program, an Acquisition Reform & Streamlining Focus Team was established under the JAST Program Integration & Analysis Directorate, led by (b)(6) [redacted] Members represented the JAST Program Office, key field activities, and the four weapon system contractors (WSCs) involved in the program at that time. Team meetings provided a forum for industry to propose and discuss with the program office and other government acquisition personnel, those measures that could cut costs and improve efficiency. One hundred and seventy-seven initiatives were submitted, and a database was established and distributed to members. Initiatives were grouped according to the program phase that they would apply to (CDP, EMD, Production and Operations & Support (O&S)) and also based on the level of approval necessary for implementation, such as:

- Can implement internally
- Can implement with approval
- Can implement if a waiver is obtained
- Cannot implement unless existing statutes are removed through legislation

Where appropriate, initiatives were implemented immediately. Others have been taken into consideration in planning for the CDP and subsequent phases. The CDP RFP was structured to allow maximum flexibility for the contractors to incorporate streamlining initiatives into their proposals. Many of the initiatives

described below that are now in place are a result of the Acquisition Reform & Streamlining Focus Team's efforts during the first two years of the JAST Program.[6, 7]

The government-industry interaction on the Acquisition Reform & Streamlining Focus Team was necessarily suspended during the CDP Source Selection (i.e., most of 1996). However, the team was reactivated during 1997, with Lt Col Bruce Caughman as the new lead. The emphasis will now be placed on planning for the EMD and Production phases.

8.2.2 Electronic Source Selection

Electronic commerce has been a major thrust of acquisition reform since the early 1990s. Some of DoD's first efforts focused on the electronic procurement of relatively low-cost, non-developmental and/or commercially available items. However, prior to the JAST Program, there was little experience or capability within DoD to perform electronic source selections for major, high technology research and development activities. The JAST/JSF Program has been a pioneer in this area.[8]

Source selection was at its most "paper-intensive" in the 1960s, when Total Package Procurement was in vogue. Contractors' proposals were delivered to the government literally by the truckload. These proposals required armies of evaluators, who in turn generated still more paperwork. The whole operation was lengthy and expensive, and when source selection was completed, the decision makers insight into the evaluation process was problematical.

How electronic source selection (ESS) works: The JSF Program Office receives industry proposals electronically, usually on storage media such as CD-ROM to avoid present-day security issues associated with transferring proprietary information over the Internet. Proposal information is then entered into a database and evaluation is performed on a local area network (LAN) consisting of:

- A system server
- Individual workstations for evaluators
- A conference room for meetings and presentations with two main workstations plus a number of "repeater" screens (so everybody can see the same thing at once)

The LAN is self-contained, and accessible only within the source selection office spaces. From their workstations, evaluators have access to the proposals themselves, and to the database. Evaluation software provides "worksheet" screens with spaces for specific responses (ratings in specific areas, or yes/no decisions) and for evaluator comments; voting screens; display screens; and a variety of predefined formats for briefings, reports and documentation.

Benefits: ESS provides the following benefits relative to the traditional paper-based process:

- Evaluation network provides all evaluators with immediate access to any desired information, displayed in convenient standardized formats. Evaluators do not have to search through paper proposals, notes, and reports.
- System automatically inputs evaluators' responses, votes, and comments into the database for future reference.
- Documentation and reports, briefings to the SSA, debriefing info to offerors, etc., are generated automatically.
- Decision makers have access to all information received or generated during the source selection—excellent insight into source selection process.
- Electronic backups provide an audit trail and a record of the entire process.
- **Bottom line**
  - More rapid completion of the source selection, with corresponding cost savings for government and industry

– More thorough evaluation, better insight and documentation, leading to a reduced likelihood of protest

The following table illustrates the savings that were achieved in the first JAST source selection BAA, involving 154 proposals, each 30 pages long. In addition to the tangible savings illustrated, the evaluation team felt that the evaluation was also *better* than it would have been by the traditional process:

> Assessment of all ten highly experienced evaluators was that this process was the most thorough and efficient proposal evaluation in which they had ever participated. Thus, even if there were no fiscal savings [which there were], the efficiency and thoroughness of the process is adequate justification for using paperless evaluation processes.[9]

Table 26: Comparison of Electronic vs. Traditional Process for JAST BAA 94-1[10]

Resources Required:	BAA 94-1 (actual)	Traditional Process (estimated)	Savings
Voting Evaluators (10 people, O-6/7 and GM-15/SES)	2 weeks	8 weeks	6 weeks (300 man-days)
Cost & Technical Advisors (20, O-4/5 and GS-13/14)	2 days	3 weeks	13 working days (260 man-days)
Post-evaluation documentation	Immediate	2 months	2 months
Paper (sheets)	6,000	136,000	130,000
Total time, initial planning through award	4 months	12 months	8 months

Approach: Because there was little in the way of existing tools or precedents, JAST did not try to do everything on the first try. For BAA 94-1, the entire solicitation was published in the *Commerce Business Daily* (*CBD*). Evaluation was accomplished electronically, but "paper" contracts were then used for the actual awards. Since that time, the JAST/JSF Program has applied the experiences and lessons learned from each source selection to continually refine and expand its ESS capabilities, always in accordance with the following principles:

- Reliability (keep it simple)
- Incremental improvements in capability
- *Always protect the integrity of the procurement process.* There is no such thing as an "experimental" source selection. Each one involves the award of real contracts to real companies, with the possibility of a real protest or nullification if the process is compromised.

The chief areas of improvement have been the use of electronic solicitations (first by diskette, and more recently via the Internet) with the *CBD* used only for announcements/synopses; gradual hardware and software upgrades; and the use of electronic contracts including security forms, financial forms, signatures, and any amendments.

In the first source selections, the emphasis was on rapidly narrowing down from a large number of proposals (154) in a broad range of subject areas, and identifying those that were of the most interest to the program. As the program progressed, the trend was toward smaller numbers of more highly qualified proposals. Over the course of the Concept Definition and Design Research (CDDR) contracts (BAA 94-2) and several Technology Maturation contracts (BAA 94-2 and subsequent) the JSF Program Office gained experience with source selections involving progressively more in-depth technical evaluation, larger contract values, more intense competition, and a variety of other new challenges.

Lessons Learned: The program consistently met these challenges, while continuing to build upon its electronic procurement capabilities. The early successes in ESS were a key element in establishing the

credibility of the JAST Program, and gaining support to implement other acquisition reform initiatives. A few of the most important lessons learned along the way include:

- Evaluation software and hardware should be specified, as well as certain proposal format items (e.g., file name conventions for the different parts of the proposal, tab locations, etc.). This is necessary to insure that all proposals will be readable, and to facilitate the entry of proposal information into the evaluation database. This was not done in BAA 94-1, and it took 1.5 days to input the proposals. Hardware, software, and file format were specified in BAA 94-2, and a similar number of proposals were input, more readably and more accurately, in just half a day.
- Don't skimp on hardware. Large monitors for readability, graphics, multiple windows, and briefings; a sufficient number of workstations (including an allowance for one or more going down during the source selection); RAM, server, processing power, network capacity, high capacity devices for proposal submission—there's no such thing as too much capability in any of these areas.
- There are particular challenges to performing an extremely rigorous technical evaluation. Electronic processes should be used when they allow tasks to be accomplished better, faster, and/or cheaper than traditional paper processes. However, some tasks are easier using paper, and a certain degree of flexibility should be maintained. For example, it is usually easier to read graphs or drawings on paper. Something as simple as laying out several pages side-by-side, to get a big-picture perspective, is impossible on a computer screen, but easily accomplished with paper. Paper and computers together are more powerful than either separately. It is important to keep the focus on goals having real value—i.e., the time and cost of the source selection and the quality of the result—rather than just fixating on the amount of paper used, or not used.

The CDP source selection was a critical test for the JSF Program. By that time JSF was designated as an ACAT I D major acquisition program and the CDP contracts would be worth close to $1 billion each. All expected bidders were familiar with the JAST program and had invested considerable resources in the development of their weapons system concepts and their proposed demonstration program plans. So, no "non-starter" proposals were expected. The CDP source selection would require thorough evaluation of every aspect of the proposals; and of course would have to be conducted with complete integrity.

For these reasons, the JSF Program Office was extremely careful, and did not take any shortcuts. Every precaution in so far as possible was taken to insure that there would be no basis for a protest. Nevertheless, the process was highly streamlined compared to previous major source selections. The entire process was electronically based, from initial draft RFP through final contract award. The ESS system facilitated the creation of extremely thorough documentation, including briefings to the SSAC, SSA and debriefing materials for the offerors. As noted in the JSF nomination for the Packard award, *"It is a tribute to the thoroughness, rigor and integrity of the overall JSF CDP source selection process that a major airframe manufacturer did not protest the decision."*[11]

8.2.3 Additional Contracting Initiatives

In addition to the use of electronic/paperless operations at every step in the contracting process, the JSF Program practices a variety of initiatives, which emphasize streamlining, government/industry teamwork, pursuit of "best value," and the elimination of non-value-added oversight. Several of these initiatives, applicable to the period from the initial pre-solicitation announcement, through contract award, are described below.

In-house source selection authority: To streamline program operations, the JAST Program Office was empowered to accomplish as much of its business as possible without having to obtain outside approval. To this end, the JAST Charter stated:

> The JAST Program is authorized to establish an in-house contracting ability (to include source selection authority), although it is envisioned that most activities will be passed to the services for execution. When asking the services to execute activities, the JAST Program will provide written direction and appropriate

> funding. Close coordination with USD(AR) [Under Secretary of Defense for Acquisition Reform] will be maintained to provide a resource organization that can implement pilot efforts.[12]

The CDP source selection was the only one for which the SSA was outside the Program Office. Almost all functions associated with source selection are normally performed internally. Cost or technical evaluators come in from the field activities to participate in JSF source selections. NAVAIR has been the Contracting Agency for most of the JSF source selections, with contracting support provided by NAVAIR personnel assigned to support JAST/JSF.

Broad Agency Announcements (BAAs): As much as possible, the JSF Program uses streamlined solicitations. BAAs are not subject to all of the regulations and requirements that apply to traditional RFPs. Specifically, BAAs allow the following:

- Abbreviated solicitation and proposals
- Multiple proposals by a single contractor
- Indefinite number of contracts awarded as desired, including multiple awards to one contractor
- Partial contract awards—allows customer to choose specific portions of proposed work

BAAs are generally used for scientific research and early, conceptual studies. Program Research and Development Agreements (PRDAs) are similar, and are commonly used by the Air Force laboratories. BAAs and PRDAs were used for all contracting activities in the early stages of the JAST Program, and are still used for most of the solicitations related to Tech Mat or similar activities. However, BAAs are specifically not permitted in contracting for the development of a specific system or hardware item. Therefore, JSF used RFPs for the CDP weapons system prime contracts and propulsion system contracts. Likewise, RFPs will be used to solicit proposals for the EMD phase contracts.[13]

Short Form Research Contracts: Where appropriate, the JAST program has used Short Form Research Contracts (e.g., BAA 94-1 and 94-2 contracts). They are short, clear, and concise, allowing rapid completion of contract negotiations and reducing the manpower subsequently required to administer them. Both the Program Office and the contract awardee benefit from these savings.

Succinct solicitations/Page-limited proposals: In all of its procurement activities, the JAST/JSF Program has utilized succinct solicitations, and placed limits on the length of offerors' proposals in order to streamline the source selection process. For the CDP Source Selection, the proposal page count limitations are as shown in Table 27. The total was only 769 pages, plus one data tape, a limited number of foldouts/drawings, and contract documentation. By comparison, the proposals for the equivalent phases of other programs have amounted to several thousand pages in length.

Table 27: CDP Proposal Page Limits

Section Number	Section Name	Page Limit
I.	Executive Summary	3
II.	Affordability	
	Preferred Weapons System Concept	200
	Supporting Data (Electronic and/or Paper)	200
	Propulsion Data Tape	1 Tape
	Foldouts/Drawings	15 (3 Copies)
	Unit Recurring Flyaway Cost	*
	EMD Cost	*
	Operation & Support Cost	*
III.	Concept Demonstration Program	
	Technical Approach	200
	Management Approach	50
	CDP Contract Cost	*
	* These four sections not to exceed 100 pages total	
IV.	Relevant Past/Present Performance	16
V.	Contract and Documentation: Standard Form 33 (hard copy) and Model Contract as required.	
	Total	**769**

Industry participation in RFP development: The industry participated in three RFP development meetings prior to the first draft RFP release for the CDP contracts. The Program Office RFP team and industry together drafted:

- Statement of Objectives
- Evaluation Standards
- Proposal Page Limits
- Evaluation Criteria
- Proposal Preparation Instructions
- Design Guidelines

The final RFP was therefore a product of close government-industry cooperation, and reflected a consensus among the offerors of how much information would be required to fairly present and evaluate their proposed weapons system concepts and demonstration programs. The offerors' relative ability to second-guess the evaluation standards was not a factor in the competition, because all offerors knew the standards up front.[14]

Performance-based specifications/reduced use of MILSPECS: It is the philosophy of the JSF Program to inform industry *what* is needed, but not to dictate *how* a need must be met. The CDP RFP actually contained *no* minimum requirements, but allowed the contractors complete freedom to trade off cost and performance to achieve their most cost-effective solution.[15]

JSF contractors are encouraged to utilize commercial standards and "best practices" (whether commercial or military), and to make recommendations to the Program Office regarding what specifications, if any, should be used in each situation. Traditional specifications and standards (such as MILSPECS and MIL-Standards) are generally applied only under the following conditions.

- When identified by the contractors as the best available guidelines for a particular design task
- For guidance only, rather than as contractual requirements

While MILSPECS have their place, (in some cases industry uses them to define "best practices.") the important thing is not to mindlessly burden contractors with a multitude of specifications—which often

contain buried references to other specifications, ad infinitum—as contractual requirements. This has traditionally forced contractors to generate tremendous quantities of documentation to show compliance with each one, whether directly or indirectly referenced in the contract. Using MILSPECS/MIL-Standards for guidance only allows contractors to benefit from the data and accumulated experience represented therein, without the formal reporting burden, and have the freedom to disregard any irrelevant, "cascading" requirements.

Common cost models: In the CDP Source Selection, cost estimation was performed using cost models established beforehand by the Program Office and the contractors. Offerors had access to the models during their proposal development efforts, but did not submit cost estimates in their proposals—only the input data for the models. Technical review of the input data was conducted as part of the source selection process. The cost estimates used in the source selection were then generated by entering the provided input data into the common cost models. This avoided ambiguity or unevenness in the evaluation of cost estimates.

Contractor-Proposed Statement of Work (SOW) in Response to Jointly Developed Statements of Objectives (SOO): In all program activities, the Program Office does not specify detailed SOWs. Solicitations contain only a broad SOO, which is usually based on extensive prior dialogue with the prospective offerors. Offerors then develop and propose their own SOW, containing those activities which they believe are essential to achieving the stated objectives.

For example, the CDP RFP contained a 4-page Statement of Objectives (SOO) identifying the top level objectives of the CDP. Based on these objectives, the offerors were required to submit a Statement of Work (SOW) describing their proposed program. The Contract Deliverable Report Lists (CDRLs) are also developed by the contractors, rather than dictated by the government. The emphasis is on activities that are essential to the achievement of the key program objectives. Eliminating unnecessary tasks along with reporting requirements minimizes cost.

Discussions With Contractors: During the source selection process—while proposals are being evaluated—every effort is made to reconcile any apparent discrepancies or misunderstandings with the offerors. The goal is to insure that the final evaluation is based upon the most realistic assessment of each contractor's proposed concept and/or capabilities to perform the proposed work—in other words, that the award is made on the objective basis of Best Value, and not just to the Best Proposal Writer.

For the CDP source selection, the JSF Program shared an unprecedented amount of key process information before, during, and after the source selection. The contractors were given access to the government's evaluation tools. Detailed government analysis and clarification requests/deficiency reports (CRs/DRs) were provided to the offerors during the evaluation. Offerors could respond to a deficiency report by:

- Agreeing with the deficiency and correcting it
- Agreeing with the deficiency and not correcting it (essentially saying, "We have traded off this capability for lower cost in accordance with the Cost As Independent Variable [CAIV] concept")
- Disagreeing with the deficiency and providing substantiation for their position

Upon completion of the source selection, one of the successful offerors commented that the discussions were so comprehensive, that they anticipated most of what would be presented in the debrief (see below).[16]

Debriefs: Upon completion of each source selection effort, the JSF Program Office provides all offerors—successful and unsuccessful—with extensive debriefs. This helps avoid protests by providing the unsuccessful bidders with accurate information as to why their proposals were not selected; and allows all contractors to develop the best possible responses to future JSF solicitations and to avoid repetition of misinterpretations.

At the debrief following the CDP source selection, offerors were provided with:

- A 150-viewgraph presentation (from the SSAC brief)

- A copy of the Source Selection Decision Memorandum (edited to avoid disclosure of contractor proprietary information to competitors)
- A copy of the Proposal Analysis Report (similarly edited)

Offerors were given the opportunity to review these materials and then to ask additional questions. The unsuccessful offeror and both successful offerors stated that this was the most useful debrief they had ever received.[17]

8.2.4 Contract Execution

Direct electronic access to contractors' management information systems (MIS): The JSF Program Office has direct on-line access to the CDP prime contractors' information systems and databases. Contractor personnel place information into an electronic data library as it is created. This provides JSF Program Office staff with *insight* into the contractors' progress, data, results, etc., without the need for detailed administrative *oversight* through deliverable reports and formal reviews. The number of CDRL items is thereby reduced—10 for one CDP prime contractor and 14 for the other, compared to hundreds of deliverables for traditionally managed programs at a comparable stage of development.

Those deliverables that are required are submitted electronically. This applies not only to the CDP prime contracts, but also to many smaller efforts including the Tech Mat programs. Video teleconferencing (VTC) is often used for management team meetings and industry-government IPT communications, reducing the need for travel by program personnel.

IPT-managed engines: In the past, engines have either been Contractor Furnished Equipment (CFE) or Government Furnished Equipment (GFE); the JSF engines, however, are "IPT-Managed Engines." The Rolls-Royce and Allison STOVL-specific propulsion components were generally defined as "CFE" in the sense that they are funded through the WSC. Propulsion system "cruise engine" components that are required for the CTOL/CV demonstrator aircraft were generally defined as "GFE" in the sense that they are funded directly to P&W. Despite these differing funding methods, the government/P&W/WSC Propulsion IPT jointly manages the development and delivery of the entire propulsion systems (i.e., the engine turbomachinery, the exhaust system/nozzle and the STOVL components), as well as the refinement of the final operational versions. In this environment, the JSF WSCs have Total System Performance Responsibility (TSPR) and design responsibility for their propulsion systems, but the Propulsion IPT jointly manages all modifications to the F119 engine as well as development of the other propulsion components.

The IPT-Managed Engine concept ensures the government sufficient insight into the propulsion system development, and brings the full benefit of the government's substantial technical expertise on propulsion system development in general and on the F119 engine family in particular. These are the traditional benefits of GFE engines. But IPT management also establishes the WSC as the single integrator of the lift systems and the cruise engine. That is a characteristic of the CFE approach, and in the case of the JSF it is essential, since the integration of the propulsion system and flight controls is extremely WSC-specific and fundamental to demonstrating the viability of the WSC-proposed STOVL concepts.

Earned value management: The JSF Program tracks cost/schedule performance of its contractors by the Earned Value method. The basic principle of Earned Value is that payment is made on the basis of work actually accomplished. Starting with the overall Work Breakdown Structure (WBS) for the contract, each project is broken down into "work packages" with defined exit criteria and milestones to indicate completion. A schedule and budget are assigned to each work package. The packages are then projected onto a timeline, which becomes the Integrated Master Schedule (IMS). Resources (manpower, facilities, etc.) are assigned, and the timeline is checked to insure there are no conflicts (e.g., multiple work packages open simultaneously requiring the same resources). A total budget projection is built up from the budgeted cost of all work that is scheduled for each reporting period.

Performance is tracked using the following data:

- Budgeted cost of work scheduled (BCWS)—the original plan
- Budgeted cost of work performed (BCWP)—the "earned value," i.e., the value (based on budgeted cost) of those tasks actually accomplished in a given period
- Actual cost of work performed (ACWP)—the actual cost incurred in a given period

Three primary metrics are derived from these data:

- **Cost variance:** CV = BCWP - ACWP
- **Cost performance index:** CPI = BCWP/ACWP (may be calculated for a given reporting period, or cumulatively since the beginning of the contract)
- **Schedule variance:** SV = BCWP - BCWS

CV and CPI are two ways of expressing the relationship between actual vs. budgeted cost, of the work actually performed. In other words, they provide a way to compare the value earned, with costs incurred. This can be used to estimate the likely total cost upon completion of the contract. Positive cost variance (or CPI > 1) means the program is below budget, while negative cost variance (or CPI < 1) means it is over budget. Schedule variance is a way of comparing the work performed to the work scheduled, without regard to actual vs. budgeted cost. Positive schedule variance means that the program is ahead of schedule, while negative variance means it is behind schedule.

The same information can be represented graphically by plotting BCWS, BCWP, and ACWP on a common scale, as in Figure 160. If the BCWP line is above or below the BCWS line, the work is ahead of schedule or behind schedule, respectively. If the ACWP line is above or below the BCWP line, the project is over or under budget, respectively, for the *work actually accomplished*.

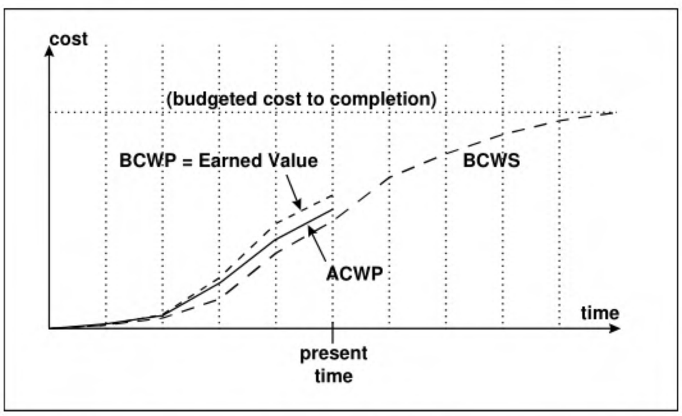

Figure 160: Earned Value Example, Showing Positive Cost and Schedule Variance

It may be tempting to compare ACWP with BCWS—i.e., the actual vs. budgeted cost at a given point in time. However, that comparison would be questionable because it is not based on equal amounts of work. Variance between ACWP and BCWS could be due to either the work being ahead of schedule (which is good), or over budget (which is bad)—and these two numbers alone do not provide any insight into which condition, or combination of conditions, exists.

Earned Value is not an entirely new concept, nor does it guarantee successful execution. It is similar to what used to be called Cost-Schedule Control System Criteria (CSCSC). While it provides a logical basic framework, the process is still dependent upon sound accounting principles, appropriate definition of work packages, and accurate administrative procedures.

8.2.5 Paperless Daily Operations

Program documents and briefings are stored electronically on a shared server where program personnel can have access to a tremendous quantity of information regarding all aspects of the program, without leaving their desks. If the Program Office tried to store the same amount of information in hard copy format, the physical space required would be enormous. Program briefings are normally presented electronically. The Internet is commonly used to access and disseminate information among the JSF Program Office, the supporting field offices, and other organizations with which the Program Office interacts. (When unclassified but sensitive information is involved, encryption software is used. Classified information is handled by appropriate methods.) The Internet provides increased efficiency by disseminating information more quickly, to a wider audience, with less manpower, than would be required for other means of transmission.

8.2.6 "Best of Breed" Concept

In all of its business practices, the JSF Program has been able to look at how each service accomplishes any given function, and pick the method that is most streamlined and/or best suited to the needs of the program. This is one of the easiest streamlining techniques to implement, because it only involves proven processes. The services have generally been very cooperative in accepting others' ways of doing business.[18, 19]

8.2.7 Sharing Experience, Processes and Tools

The JAST/JSF Program has continually worked to disseminate new processes, tools, experiences, and lessons learned throughout the defense and U.S. Government acquisition communities. JAST was one of the first DoD programs to have its own site on the Internet. From very early in the program, the Web site was used to distribute information about the latest acquisition reform initiatives the program was pursuing. Diskettes containing ESS tools and applications were made available by request, free of charge, as were detailed papers describing lessons learned from the early JAST ESS efforts. Program personnel gave presentations at the Defense Systems Management College (DSMC), Naval Air Systems Command (NAVAIR), Naval Sea Systems Command (NAVSEA), and other government acquisition agencies on the use of electronic source selection processes. The program has produced several articles, which have appeared in the *DSMC Program Manager* and other prominent publications.

These efforts have accelerated and/or enhanced the widespread implementation of many new practices, including:

- ESS
- Program Web sites, and use of the Internet for routine communication
- CAIV (described in the following section)
- STT and QFD processes
- M&S / Simulation Based Acquisition

A large number of programs and government agencies have benefited from JAST/JSF experiences and lessons learned in these and other areas.

8.3 Cost as an Independent Variable (CAIV)

JSF is a Flagship program for the implementation of the CAIV policy established in a USD(A&T) policy memorandum in July 1995:

> I am committed to establishing a process whereby cost is an independent variable in programmatic decisions, and cost goals are set in each program phase. I believe this process will allow us to provide the most performance for an affordable cost. The overall result will be to increase the effectiveness of our forces

> while remaining within the bounds of our resources... Effective immediately, I am adopting the policy described… for all ACAT I D programs.[20]

As a Flagship program, JSF is not only practicing CAIV, but also developing techniques and applications and cataloging lessons-learned for the benefit of other programs. JSF was effectively carrying out this policy even before CAIV was formally articulated by DoD.

From JAST's beginning, affordability has been a central theme—not just initial acquisition cost, but also sustainment costs. A LCC model was adopted during the first few months of the program, and has been subsequently refined. This is probably the most mature LCC model ever to be used in a program at such an early stage. LCC savings opportunities were identified through the efforts of the JAST TM Directorate and the contractors' Concept Exploration studies. Affordability drove several key decisions early in the program—including the single engine, a single seat, and the highly common "tri-service family of aircraft" decisions. Employing the QFD methodology, specific advanced technologies were then prioritized based on their contribution to LCC savings and warfighting benefits. Cost and performance were equally weighted. Tech Mat focus and direction is assessed at least annually to ensure continuing alignment with program objectives. Cost targets were initially established for Average Unit Recurring Flyaway Cost and EMD cost, and are being established for LCC. These serve as baseline independent variables for requirements and technology affordability trades.

The mechanism for implementation of these cost/performance trades is a "continuous [Cost & Operational Effectiveness Analysis] COEA process." The JSF Program refers to this process as COPTs. *In essence, every requirement must earn its way into the system on the basis of cost effectiveness.* The COPT is coordinated with the development of each JIRD update. This link promotes iterative and interactive requirements trades and cost target development, which will culminate in a validated JORD and JSF System Specification prior to EMD. Affordable cost targets encompass process improvements and the benefits resulting from the program's Tech Mat initiatives. The COPT process participants are empowered to conduct the cost/performance trades in association with the WSCs, as coordinated through the program office. It will be through these trades that affordable JSF requirements and PWSCs evolve.[21]

8.4 Requirements

8.4.1 Requirements Facilitated From Within the Program Office

This is an unusual arrangement, but is integral to the CAIV process, and to achieving cooperation between the individual services—one of the traditional stumbling blocks in joint acquisition programs. It would be exceedingly difficult to do this in the framework of the services' traditional requirements organizations.

There could, conceivably, have been a jointly staffed JAST requirements office, separate from the program office. Such a provision was, in fact, considered in the early planning stages.[22] That could have brought the services together while maintaining the traditional "independence" of the requirements and the systems acquisition communities. However, the early program planners desired a more integrated approach. Creating a requirements group in the program office provided the best environment for continually weighing desired capabilities against cost and technical risk.

8.4.2 No Final Requirement Until EMD Entry

Delaying final requirements goes hand-in-hand with the co-location of requirements generation discussed above. Some acquisition programs are not even launched until there is a formal, validated requirements document. In contrast, JAST was established to meet a set of broadly defined needs that were acknowledged in the BUR, but with the philosophy that specific weapon system requirements should not be settled upon until the leveraging cost/performance trades have been performed, and key technologies

and concepts have been demonstrated. The JSF Program is therefore developing a series of preliminary or interim requirements documents—i.e., the JIRDs—in parallel with the program's CDP. This process will culminate in a JORD shortly before the start of EMD. This "just-in-time" approach avoids a premature commitment to formal requirements that:

- Could be excessively costly to meet
- Might fail to take advantage of available technology; or conversely
- Might depend upon immature or overly expensive technology

In summary, delaying formal requirements allows time to work the weapons system affordability, and to insure that the requirements are consistent with the available technology. The process also helps the services understand the cost of what they are asking for.

8.4.3 Strategy-to-Task (STT) Analysis and Quality Function Deployment (QFD)

The STT analysis established the framework of the JAST/JSF requirements process at the beginning of the program. This addressed a critical need, identified by the Packard Commission[*] and subsequent panels on acquisition reform, to *provide a stronger linkage between national military strategy, and weapons system acquisition decision making*.[23]

STT, developed by RAND, uses a hierarchy of objectives to establish a framework for "top-down" thinking. The end product is a traceable linkage from the highest-level national goals, down to specific weapon system characteristics. Defining the specific linkages between each level in the STT hierarchy could have been accomplished in several ways:

- **An executive exercise**—Senior service leaders decide what the relationships are.
- **A small working group**—The group deliberates and breaks down each level of activity to determine detailed relationships between items.
- **A voting "congress"** composed of warfighters and technologists from each of the services—a representative forum providing the means for open discussion and thoughtful deliberation of each item leading to a consensus on each decision.

Of these three options, the "congress" option best facilitates "jointness" and generates solid supporting rationale. Establishing a joint team of warfighters and technologists was the key to balancing objectiveness with service bias. The primary drawback to the open forum is the challenge of obtaining consensus in a group comprised of many individuals with different experiences and expertise, and with conflicting operational needs and priorities. The program office chose the QFD analytic tool to help overcome these hurdles.[24]

The details of the STT and QFD processes as implemented by the JSF Program have been discussed in Sections 2.3.2, 3.2.3–3.2.5, and 4.2.2, and therefore will not be repeated here. However, two key accomplishments of the JSF Program in these areas are worth emphasizing, as they have become a model for other programs:

- **The most comprehensive QFD flowdown ever accomplished.** No other program, before JAST, had ever carried the linkage from campaign objectives contained in the Defense Planning Guidance (DPG) all the way down to weapons system attributes, technology areas, and specific technology projects.
- **Explicit consideration of logistics and support in the STT linkage.** The developers of the STT process noted that this would be a desirable thing to do; but it was the JAST/JSF Program who took

[*] There were actually two acquisition reform panels referred to as the "Packard Commission," one in the early 1970s and one in the mid-1980s. In this document, "Packard Commission" refers to the Presidential Blue Ribbon Panel on Defense Management which was chartered in 1985, and reported its findings in *A Quest for Excellence, Final Report to the President*, June 1986.

> on the difficult task of working out the details to logistics and support functions into the requirements process on an equal footing with the traditional "shooter" operational tasks. This is a key element in driving down the JSF LCC.

(b)(6)

One of the most important contributions of QFD was to establish some common terminology and definitions that enabled the members of the different services to communicate with each other. According to [redacted] (b)(6) who was involved in the MRF Program and in the early JAST requirements analysis, "The value of this exercise (which was very high) was not in establishing firm initial requirements. It was rather to act as a translation device….In identifying the different missions and attempting to quantify the relative importance of both missions and needs, it became obvious that very careful and agreed upon definitions would be necessary. We found that the same terms were being used with very different meanings, and the primary benefit [of the initial QFD exercise] was to uncover these discrepancies and arrive at a mutual understanding of the needs. It built a strong working relationship that would be essential to a common requirements definition process."[25]

8.4.4 Modeling & Simulation (M&S)

The JSF Program makes extensive use of M&S in the requirements development process. This has, since the JSF Program began, become a major DoD-wide thrust, known as Simulation Based Acquisition. To date, JSF has used engagement-level and campaign-level constructive (and, to some extent, interactive) M&S to develop preliminary requirements, and has begun to focus on mission-level, virtual, pilot-in-the-loop simulation to support a more thorough evaluation of required avionics capabilities. Virtual Manufacturing and Virtual Maintenance are also being pursued to facilitate planning in these areas and thereby drive down the associated costs.

JSF has not, generally, developed new M&S tools from scratch. Many of the models used by the JSF Program have been around for 10 to 15 years or more albeit in earlier versions. However, JSF has taken a systematic approach to building, through selected model enhancements and a minimal number of new model developments, a complementary set of models that meet the needs of the JSF Program and other programs for requirements analysis.

The program started out by defining a set of existing "core models," and establishing a configuration management process composed of a Configuration Review Board (CRB) and a Configuration Control Board (CCB). The WSCs are represented by voting members on both of these boards. To prioritize model enhancements, the CRB periodically performs a "rack and stack" of proposed model improvements, first among all proposed improvements to each model, and then across all models. Their results go to the CCB (chaired by the JSF Requirements Director), which is responsible for determining JSF investments in model improvements. For each selected improvement, the JSF Program Office coordinates with the appropriate DoD model manager in order to avoid developing JSF-unique models. Either the DoD model manager funds and manages the proposed enhancements, or the JSF Program Office manages the changes and then provides the improved model back to the DoD model manager.

To serve as an acceptable basis for formal weapon system requirements, each model (and model modification) must be certified by a recognized authority. This process is known as Verification, Validation and Accreditation (VV&A). Because of rapid growth in the use of M&S—involving both the number of different models, and the number of different agencies using them—VV&A has become a complex issue. It was recognized from the beginning of the program that JAST (and later JSF) would have to be a proactive key player, and not just a passive "victim," in the VV&A process to succeed at M&S-based requirements development. Accordingly, whenever JSF funds a model improvement, the program also funds a "tax" of roughly 15% to perform VV&A up-front, concurrently with the modification of the model, when it is most cost-effective.[26]

Additional discussion of JAST/JSF M&S activities can be found in Sections 3.2, 4.2, and 5.2. Highlights and significant accomplishments to date include:

- The best version of the Thunder model for simulating joint campaign operations, due to JAST/JSF-sponsored improvements in areas such as threats and weapons databases. Thunder was previously used primarily by the Air Force.
- An interactive capability for Thunder.
- Incorporating logistics and support into Thunder to evaluate the impact of logistics decisions on campaign outcome.
- Preliminary demonstrations of the mission-level Virtual Strike Warfare Environment.

The program's approach to requirements evolution provides a unique window of opportunity to incorporate M&S results, including virtual simulation of relatively mature concepts, into the requirements development process. The next few years will be a critical test of this approach.

8.4.5 System of Systems

The entire JSF requirements process looks at the JSF not as an isolated asset, but in conjunction with other systems expected to be in the U.S. inventory in the early 21st century. The idea is to leverage, not duplicate, capabilities that will exist in other systems. There are two primary ways that this will improve the affordability and cost effectiveness of the JSF:

- Relying on other assets to perform some of the most demanding, but less common, missions. For example, missions requiring deep penetration into very high-threat areas could be performed by the B-2s and/or Tomahawk Land Attack Missiles (TLAMs) as appropriate. This may allow JSF requirements in areas such as mission radius and signature levels to be less aggressive, which could otherwise become high cost drivers. The issue of whether or not JSF needs to carry 2,000 lb. weapons internally is another requirements issue being studied.
- Utilizing off-board information for situational awareness and, to some extent, target acquisition/identification is a promising concept. Early JAST Concept Exploration studies indicated that near-total reliance on off-board information is neither feasible nor desirable. The best combination of on-board and off-board information is still being sought, to provide JSF with improved lethality and survivability within an affordable on-board avionics suite.

8.5 Technology Maturation

The JSF Tech Mat activities fulfill two key recommendations of the 1986 Packard Commission report:

- Apply advanced technology to reduce cost, not just to increase performance
- Demonstrate advanced technologies prior to EMD entry

Approximately one quarter of JSF pre-EMD resources are allocated to Tech Mat efforts in the areas of flight systems, propulsion, supportability and training, structures and materials, manufacturing and producibility, and mission systems. Technology investments have been selected on the basis of a balanced weighting between the potential to improve life cycle affordability, and the potential to provide enhanced capability in the other requirements "pillar" areas of survivability, supportability, and lethality.

8.5.1 Maximizing Technology Transition

Achieving transition of advanced technologies from laboratory programs into operational weapons systems has always been a challenge. General Muellner, the first JAST Program Director, stated:

> … one of the problems we have had historically is that output of our science and technology [S&T] programs never takes the demonstrations far enough so that a program manager or contractor is willing to embrace that technology. In JAST we are taking the technologies that come out of the S&T program and demonstrating them to a much higher degree. The only ones we are demonstrating are the ones our contractors say they will use if the demonstration is successful. It assures a much higher degree of transition of the S&T investment.[27]

Historically, S&T programs have not been coordinated and closely integrated with the needs of acquisition organizations for incorporation and certification of aircraft technologies. This is true both in the government and in industry. Typically in most corporations, the working level S&T engineers are rarely involved with aircraft design development. Similarly, aircraft designers are not sufficiently familiar with S&T activities and tend to rely on current practices and "what worked last time." Once an aircraft program is initiated, there is usually pressure to keep to a development timeline, which further discourages the application of unproven technologies.

The historical problem of effectively transitioning S&T programs was recognized, even before JAST started. There were cooperative efforts within the USAF Acquisition and Laboratory communities to link technology programs to the pertinent end-users. The earlier efforts of the Mission Area Technical Planning Integrated Product Teams (TPIPTs) were to achieve this linkage while securing end-user involvement and commitment. The results were generated by a TPIPT membership that represented all of the pertinent stakeholders (technologists, developers, operators and sustainers). The efforts were documented in Mission Area Roadmaps that had MAJCOM sponsorship. This approach has evolved (across the USAF) into the current Modernization Planning Process (MPP), which is now being led by the individual MAJCOMs, and still has the pertinent stakeholders as the core membership. JAST/JSF has realized more positive and evident benefits from this philosophy by virtue of a singular weapon system focus and by being a high profile, new acquisition program. This does not, however, lessen the importance of the achievements of the JAST/JSF Program. JAST/JSF has been a prime 'proof of concept' case, and has made immeasurable progress in gaining positive support among the services for this approach. It is much closer to being accepted as a DoD best practice, especially during this period of acquisition reform and the search for better, more effective business practices.

The initial challenge for the JAST TM Directorate was to formulate and execute programs involving both the acquisition and laboratory communities in such a manner that technology demonstrations would:

- Be responsive to the technology needs identified by the WSCs' design teams
- Address key risk areas and bring the technologies to an acceptable level of readiness in the eyes of the industry design teams and the acquisition community

The initiation of such demonstration programs has laid the groundwork for an affordable EMD phase, with an acceptable risk level.

The level of investment, through the traditional S&T process (laboratory-managed, Budget Category 6.3A), is typically on the order of $10 million or less in any given technology project. S&T projects are usually highly focused in a specific technology area. This is a desirable quality, and even necessary to the success of a project in the early stages of technology development. However, a weapons system program manager approaching EMD start cannot embrace technologies that have only been demonstrated in isolation. Demonstration of technology performance, payoff and compatibility with other technologies or features of a specific weapons system in an operational environment cannot readily be accomplished in small, highly focused laboratory efforts. The JAST Tech Mat strategy was therefore to "bridge the gap" between the level of readiness of technologies coming out of traditional S&T programs, and the level of readiness required for JSF EMD. This often required investments on the order of $100 million to mature integrated sets of technologies, such as the JSF Integrated Subsystems Technology (J/IST) and Multifunction Integrated Radio Frequency Aperture (MIRFS) programs described earlier.

Operators, maintainers, and the aircraft design teams have been involved in the selection and structuring of JAST/JSF Tech Mat projects from the beginning, to provide an improved level of coordination between the historically distinct laboratory, system design/development, and user communities. All of the technologies that the JSF Program is sponsoring have been identified as having a high payoff, based on balanced weighting of warfighting capability and life cycle affordability. All of the information and data from the JSF funded Tech Mat demonstrations is, by definition, transferable and available to all of the competing JSF weapons system prime contractors. This is accomplished through Associate Contractor Agreements (ACAs) or analogous provisions, and is true regardless of whether the work is performed by one of the primes, or by a specialized subsystem supplier or vendor; and includes all analysis, approaches, trade studies, and test results. The goal of Tech Mat activities is not to support any one contractor's development effort, but to mature technology so that it is available to all of the prime contractors.

8.5.2 Management: Technology Integrated Product Teams (IPTs)

Each technology area is managed and supported by an IPT, consisting typically of an IPT lead and one to three supporting members in the JSF Program Office; plus government and industry engineers residing at laboratories and development centers throughout the country. The IPT lead and immediate staff provide interface within the JSF Program Office on budgeting matters and other issues as needed. In technical matters, the IPT lead is supported by a core team that includes the lead, a deputy (who may be stationed at the JSF Program Office or at one of the field sites), and a small number of senior field site personnel representing Air Force and Navy acquisition and laboratory organizations. Overall direction, and the selection and planning of technology projects, is accomplished by the core team in conjunction with JSF warfighter and weapons system concept team input.

Day-to-day management of specific projects is normally performed by jointly-staffed project offices at the field sites: the Naval Air Warfare Centers at Patuxent River, Maryland, China Lake, California, and Point Mugu, California; Air Force laboratories at Wright Patterson AFB, Ohio, and Eglin AFB, Florida; the Air Force Flight Test Center at Edwards AFB, California; NASA; DARPA; or other locations. These project offices perform contracting functions, track cost/schedule performance of the contractors' efforts, and resolve issues or elevate them to the JSF Program Office as appropriate; but they do not perform detailed technical oversight.

At individual IPT meetings and program reviews, government members ideally function according to the principle of "insight, not oversight." They are not there to critique, "nit-pick" or independently assess the contractors' efforts, but to contribute their expertise and to always *add value*. In addition to the full-time project office personnel, government experts in specific technical disciplines are sometimes tasked part-time to support the program in this way. Cost analysts, members of other IPTs, JSF Requirements personnel (including operators and maintainers), and representatives from the prime contractors' weapons system design teams, also attend technology IPT meetings and reviews. They help to assure that the Tech Mat projects remain relevant to the technology needs of the JSF weapons system concepts, *and* to the evolving JSF warfighting requirements. In other words, advanced technologies, like current technologies must also "buy their way onto the airplane" through demonstrated cost effectiveness.

8.6 Security

It is the responsibility of the Joint Strike Fighter Security Directorate (JSF/SC) to maintain an overall security program that effectively balances the cost and risk of protecting the critical aspects of the JSF Program, including its systems and underlying technologies. The JSF/SC ensures that security costs and administrative requirements are reduced to the absolute minimum required to protect the critical enabling technologies of the JSF program. In addition, the directorate is responsible for program classification management, security policy and managing compartmentalized information. It is the ultimate goal of JSF/SC to ensure an uncompromised weapon system at IOC.

Major (later LTC) [redacted] USAF initially headed the JSF/SC. He was later to be followed by LTC [redacted] USAF, and then [redacted] USN. Each of these Security Directors has been ultimately responsible for providing the JAST/JSF program with the full spectrum of security and counter-intelligence support as well as supporting the JAST/JSF security plan. From the outset, the JAST security plan made the assumption that the traditional approach to security was not feasible because it was outdated, required too many people, and was not streamlined. It was stated that a risk-management approach to security would be more effective in reducing costs, avoiding the duplication of efforts, and lifting unnecessary administrative burdens. It was clear that the security surrounding JAST/JSF would be different not only because of the type of security that the program requires, but also because the JAST/JSF program is so oriented towards affordability.

The security surrounding the JSF is unique when compared to any other high level Air Force/Navy acquisition program in the past. Unlike the development programs for the F-117A and the B-2, the JSF Program is an overt program with classified components. From the outset, the JSF/SC wanted to avoid throwing a tight security blanket over the program. Due to the now widespread knowledge of stealth aircraft, the low observable technology being incorporated into the JSF can be acknowledged. The JSF/SC focuses on the value added and affordability from the security program management. To do this, a plan had to be developed on how the program security would operate. The Program Protection Plan (P^3), which is required for all acquisition programs by Department of Defense Instruction 5000.2, and the System Security Concept (SSC) for the JSF program encompass all security measures taken to protect the program. The first step in organizing the JSF P^3 and SSC was to establish a baseline. The baseline is the cornerstone of the protection efforts for the program and address security concerns for the entire program. As an initial JSF/SC point paper stated, "Traditional security services alone can be quite costly, inflexible and considered a burden to bear. The JAST Security Management approach should be one of judicious implementation of selected measures designed to reduce vulnerabilities to an acceptable level of risk."

The JSF/SC has three key areas of support: Operations, Foreign Disclosure and Program Protection. All three of these areas are within the direct supervision of the Director of Security. Program Protection involves the identification and safeguarding of JSF systems and technical data anywhere in the acquisition and sustainment process. Foreign Disclosure is self-explanatory. Security Operations presides over the traditional security disciplines, including personnel, physical, industrial, automated information system, and Special Access Program (SAP) security.

The JSF/SC is responsible for the training and education of all JSF government and contractor personnel in security policy and procedures. The JSF/SC conducts initial security indoctrination as well as training on safeguarding proprietary/source selection material, counterintelligence awareness, and on other briefing topics as necessary. The JSF/SC also reviews all program information and is responsible for approving information for public release. Information up to Top Secret is conveyed through the JSF Program Office to contractors and other military installations. It is important to note that the JSF/SC oversees *all* information, not just classified information. This is due to the heightened security surrounding acquisition processes that now protect unclassified technical proprietary and For Official Use Only information.

The JSF Program creates a unique security challenge due to the participation of international partners. The DoD and the JSF Program Office have formal agreements (Memorandum of Understanding/Agreement (MOU/MOA)) with the defense agencies of several countries. These MOU/MOAs allow personnel of these nations to have access to U.S. and JSF classified and unclassified information. Their level of participation in the JSF Program determines the types of information a nation receives. Specific disclosure authority has been granted to the Program Office by Assistant Secretary of the Air Force for International Affairs (SAF/IA) for Air Force and JSF information. Other information (e.g., USN) must receive release approval from a cognizant authority. The Program Office has established policies in accordance with Department of Defense and Air Force directives for the day-to-day inclusion of foreign participants. Few times in history

have partners been included in a U.S. program in the developmental phase. The international aspects of the JSF program will be dealt with in more depth in Chapter 9.

8.7 Program Review and Insight—Integrated Product Teams (IPTs)

In April 1995, (b)(6) [redacted] then USD(A&T) issued a Policy Memorandum directing an "immediate and fundamental change in the role of the OSD and Component staff organizations." Rather than operating in an independent assessment and oversight role, these staffs were to begin functioning as members of IPTs* in close cooperation with program office staffs, toward a common goal of program success and in accordance with the following principles:[28]

- Open discussions with no secrets
- Qualified and empowered team members
- Consistent, success-oriented, proactive participation
- Continuous "up-the-line" communications
- Reasoned disagreement when problems arise
- Issues raised and resolved early

That Policy Memorandum (portions of which are reproduced in Appendix B) and subsequent guidance established a structure of Working Level IPTs (WIPTs) (beyond those responsible for the actual execution of a program), an Integrating IPT (IIPT), and an Overarching IPT (OIPT). The OIPT is headed (in the case of the JSF Program) by the Director of Strategic and Tactical Systems, OUSD(AT&L), and is the highest level body supporting the DAB on program decisions. The IIPT provides coordination between the OIPT and the WIPTs. The WIPTs consist of appropriate Program Office staff, plus members of those OSD and Component organizations, which have traditionally provided program "oversight." The specific number and membership of WIPTs is determined individually for each program by the OIPT; the primary JSF Program WIPTS are listed in Table 28.[29]

* In the strictest sense, the definition of an IPT is associated with the concept of Integrated Product & Process Development (IPPD), and implies cradle-to-grave responsibility for a product. An IPT consists of representatives from all relevant functional disciplines, including designers/developers, manufacturers, users and maintainers of the product in question. As a result of recent acquisition reform emphasis, the term IPT has come to be used somewhat more loosely. There are now many different kinds of IPTs in the JSF Program and throughout DoD, all of which reflect some integration across traditional functional and/or organizational (such as inter-service or government-contractor) boundaries, but not all of which fit the original definition of an IPT.

Table 28: Major JSF Program "Working Level" IPTs[30]

Group	Membership	Roles/Products
Operational Advisory Group (OAG)	JSF, service users (warfighters and maintainers)	Develop weapon system requirements: Joint Initial Requirements Document (JIRD) /Joint Operational Requirements Document (JORD)
Force Process Team (FPT)	JSF, service users	Evaluate weapon system attributes through modeling, simulation & analysis; support JIRD/JORD development
Cost & Operational Performance Trade (COPT) Working Group	JSF, Users, OSD PA&E	Produce interim COPT results, recommend appropriate CAIV targets and areas for further tradeoff studies.
Cost Estimating Group / Affordability IPT	JSF, service and OSD PA&E cost estimators	Prepare and coordinate formal program cost estimates
Combined Test Working Group	JSF, OSD Director Operational Test & Evaluation (DOT&E) and Director Test Systems Engineering & Evaluation (DTSE&E) staffs, service test agencies and acquisition staffs, users, industry.	Plan and integrate development and operational test activities. Develop the Test & Evaluation Master Plan (TEMP) prior to MS II.
System Threat Working Group	U.S. Intelligence Community	Define, analyze and document relevant anticipated threats in the System Threat Assessment Report (STAR)

* This is *not* an exhaustive list, and only includes IPTs that perform program review/insight, not those responsible for program execution (such as the Systems Engineering IPTs).

The process requires two-way cooperation. On the part of OSD and service staffs outside the program office, it requires willingness:

- To relinquish the traditional roles of "direction" and "oversight"
- To participate and *support* the program on a continuous basis

On the part of the JSF Program Office, it requires a proactive effort to keep OSD and service organizations informed of program status and issues, and to seek outside participation as appropriate. To this end:

> … it is the program's intent to share information on a routine basis using the Working Level and Overarching integrated Process Team (IPT) process. Through this IPT approach, key staff functions and senior leaders will be able to provide early input to program strategies and plans, help resolve issues in a timely manner, and maintain continual insight to the program and contractors' progress toward critical performance goals…. Up front integration of activities is intended to ensure that everyone has insight into the product and processes of JSF.[31]

JSF became an ACAT I D program, and therefore subject to the new insight and review structure, in May 1996–just six months before the planned CDP contract awards. The Milestone I decision process was very challenging, and entailed more meetings than originally planned, in spite of the fact that the necessary reviews had, in substance, been accomplished from September 1995 through February 1996. This was mostly due to the "newness" of both the milestone review policy, and the JSF Program's ACAT ID status.

While "six months prior to milestone decision" was specifically cited as the *wrong* time to begin interacting, there was little choice because JSF was only declared an ACAT I D program exactly six months

prior the planned CDP contract award. So, the Milestone I decision had to be accomplished within that timeframe. The policy guidance on IPT-style operations was also new, and not yet fully understood/accepted by all involved.

Due in part to strong support from the very highest levels, including [redacted] and the acting Air Force SAE, Ms. Darlene Druyun, the Milestone I decision was, in the end, accomplished without major re-direction from the CDP approach approved previously. This had the fortunate result of not delaying the CDP contract awards.[32, 33]

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1 Muellner, George K., Lt Gen USAF, Interviewed by [redacted] in *Aerospace America*, September 1995, pp. 14-16.
2 [redacted] CAPT USN, Interviewed by [redacted] 26 January 1998
3 [redacted] Deputy Director, JSF Business & Financial Operations, Interviewed by [redacted] 16 January 1998.
4 *Charter for the Joint Advanced Strike Technology (JAST) Program*, JAST Program Office, approved by Dr. John M. Deutch, Deputy Secretary of Defense, 12 August 1994.
5 Schwartz, Fred, SES USAF, JSF Program Technical Director, Interviewed by [redacted] 13 January 1998.
6 [redacted] 1998.
7 *Joint Strike Fighter (JSF) Program Nomination for the David Packard Excellence in Acquisition Award*, JSF Program Office, Arlington, Virginia, 17 January 1997.
8 [redacted] "The Joint Advanced Strike Technology (JAST) Program: Streamlined Acquisition and Paperless Proposal Evaluation Process," *Program Manager*, September–October 1994, pp. 33-38.
9 Ibid.
10 Ibid.
11 *Joint Strike Fighter (JSF) Program Nomination for the David Packard Excellence in Acquisition Award.*
12 *Charter for the JAST Program.*
13 [redacted] 1994.
14 Joint Strike Fighter (JSF) Program Nomination for the David Packard Excellence in Acquisition Award.
15 Ibid.
16 Ibid.
17 *Ibid.*
18 Muellner, George K., Lt Gen USAF, Principal Deputy to the Assistant Secretary of the Air Force (Acquisition), Interviewed by A. Piccirillo and D. Aronstein, 22 January and 28 January 1998.
19 [redacted] JSF Operations Manager, Interviewed by D. Aronstein, 20 January 1998.
20 [redacted] Under Secretary of Defense for Acquisition & Technology (USD[A&T]), Policy Memorandum: *Policy on Cost-Performance Trade-Offs* [CAIV], 19 July 1995.
21 *Joint Strike Fighter Single Acquisition Management Plan* (*SAMP*), Joint Strike Fighter Program Office, Arlington, Virginia, 11 October 1996.
22 *Joint Advanced Strike Technology Program* (Briefing), 25 August 1993.
23 *A Quest for Excellence: Final Report to the President*, Presidential Blue Ribbon Panel on Defense Management, June 1986.
24 Joint Advanced Strike Technology Program Strategy to Task to Technology Analysis, JAST Program Office, Arlington, Virginia, July 1995.
25 [redacted] USAF ASC/LU, Letter to D. Aronstein, 1 May 1998.
26 [redacted] Maj USAF, JSF Requirements Analysis IPT Lead, Interviewed by [redacted] 9 April 1998.
27 Muellner, 1995.
28 [redacted] Under Secretary of Defense (Acquisition & Technology), Policy Memorandum, Subject: *Reengineering the Acquisition Oversight and Review Process*, 28 April 1995.
29 [redacted] *Introduction to Defense Acquisition Management*, Defense Systems Management College Press, Fort Belvoir, Virginia, June 1996.
30 Joint Strike Fighter Single Acquisition Management Plan.
31 *Ibid.*

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[32] Schwartz, Fred, SES USAF, JSF Program Technical Director, Interviewed by A. Piccirillo and D. Aronstein, 13 January 1998.

[33] (b)(6) [redacted] Lt Col USAF, JSF X-35 Deputy Program Manager, Interviewed by D. Aronstein, 18 December 1997.

9 International Participation in the Joint Strike Fighter Program

9.1 Background

The world has become increasingly integrated and this fact also affects a nation's defense arrangements. In a shrinking world where the United States intends to protect its vital interests, extensive international commitments and reduced Defense budgets influence the U.S. to share the cost and responsibility of this protection with its Allies and regional powers whose national interests complement those of the United States. This is recognized by the International Programs Security Handbook, which states:

> International Programs are…a fact of life. They will require sharing technology, classified military information…and controlled unclassified information…with allies and other friendly countries. The risk of its being exploited and falling into the wrong hands must be taken into consideration. DoD officials must therefore understand how to protect the military capability of our Armed Forces which is represented by the related technology and other controlled information, and, at the same time, support international programs[1]

There are many significant precedents for international cooperation in advanced weapons system development. For well over fifty years, the U.S. and the UK have collaborated on programs of the utmost importance to both nations, beginning in World War Two with radar, the Ultra decryption program, and the Manhattan Project. In the 1950s, the U.S. collaborated with the UK on the development of the Bristol Pegasus engine and, later, of the Hawker Kestrel and its successor, the Harrier. Versions of the AV-8B Harrier are presently operated by the U.S. Marine Corps and the UK Royal Navy, both of which will eventually be replaced by STOVL-variant JSFs. The Netherlands, Norway and Denmark all participated in the F-16 Multi-National Fighter Production (MNFP) Program, and are considering replacing their F-16s with CTOL JSFs. Canada, another close ally of the United States, has an interest in replacing its CF-18s with CTOL JSFs. More and more countries are becoming increasingly interested in purchasing JSFs.

The United States has decided to develop the JSF with an eye to the international market, and to cooperate with various countries during the development phase. There are several reasons for this. One good reason is that U.S. national security has historically been a function of collective security, which is enhanced by cooperative development of weapons systems. Another reason is financial. Affordability is the single most important factor driving the JSF Program. Foreign government and industry participation reduces development costs, brings in additional expertise, provides access to unique test facilities, encourages competition, and leads to longer production runs and lower production unit costs. Once a weapon system is in service, interoperability of equipment within an alliance simplifies maintenance and reduces the logistical footprint of the entire force, thereby lowering costs while improving the effectiveness and flexibility of the force. In balance, these benefits increasingly outweigh the risks and additional complexity of international cooperation in the modern defense environment.

9.2 History of International Participation in JAST/JSF

International participation was part of the vision of the JAST Program from its inception in the fall of 1993. The OSD intended for JAST to serve as a "pilot program" for new ways of doing business in the post-cold-war era, and as such, was expected to lead the way in defining how international participation in advanced weapons system development could best be accomplished.

9.2.1 Initial JAST Approach

In November 1993, while JAST was still in the planning stages, the newly selected program director, then-Brigadier General George K. Muellner told the transition planning team that he believed JAST Program products would have considerable Foreign Military Sales (FMS) potential and that FMS potential

must be considered. He also warned the JAST planning team that they had to be prepared for international involvement, but that participating nations were expected to bring money as well as intellectual property.[2]

This position was reiterated by a DSB Task Force chartered to examine the JAST Program during its first year. The Task Force's report noted:

> Foreign participation in the development of next-generation strike fighters should be measured by credible expectation of value added, and focused on market exploitation. Next-generation strike fighters should be designed with the foreign market in mind; this implies affordable cost, and versions of the aircraft in which technologies can be adjusted to the export market.[3]

Because JAST aims to ultimately provide a replacement for USAF F-16s, USMC F/A-18C/Ds and AV-8Bs, and (in conjunction with the F/A-18E/F) USN F/A-18C/Ds, other nations operating those aircraft types would naturally be interested, as more than 1700 F-16s and 400 F/A-18s have been delivered to foreign governments. Harriers, though less numerous, are also in service with several nations. The operators of all of these aircraft will be seeking replacements as they age out of the inventory early in the 21st century. This creates a large, potential export market for JAST products.

Furthermore, many of the nations interested in procuring the next-generation U.S. strike aircraft would also want to participate in its development, for both economic and political reasons. The U.S. Department of Defense was ready to accept such participation provided that each participating nation could "bring something to the table" both financially and technically.

9.2.2 Early Foreign Interest in JAST

The UK RAF showed considerable early interest in JAST. The UK Ministry of Defense (MoD) considered participating in JAST and proposed to assign two RAF staff to the JAST Program Office. One would have been a serving officer for the requirements area, and the second would have been a civilian scientist in the technology area. This proposal appeared to be connected with a developing RAF requirement for a Future Offensive Aircraft (FOA), a relatively large, "high-end" CTOL fighter/attack aircraft.[4]

However, JAST was not ready to accept this level of foreign involvement right away. While the specific direction of the JAST Program was not yet clear, it was likely that any future strike weapons systems would involve low observables and other sensitive technologies. The details of international participation in the program would have to be worked out carefully. In the fall of 1994, JAST Program personnel began detailed planning for international participation. Simultaneously, JAST became an international program by fiat rather suddenly in October 1994, when Congressional FY95 budget legislation directed the absorption of the U.S./UK ASTOVL Program into JAST.

9.2.3 U.S./UK Collaboration on ASTOVL Programs

(Note: the ASTOVL programs are discussed in much greater depth in Appendix A.) U.S./UK collaboration on V/STOL aircraft dates back to 1957. Development of the Bristol Pegasus engine for the Hawker P.1127 V/STOL lightweight fighter/attack aircraft received U.S. support through NATO's Mutual Weapons Development Program. Shortly thereafter, the U.S. also provided support to the development of the aircraft, which evolved into the Harrier, the first operational V/STOL airplane. The Harrier entered service with the UK Royal Air Force (as the GR.1) in April 1969 and with the U.S. Marine Corps (as the AV-8A) in 1971. The AV-8B Harrier II grew out of design studies by McDonnell Douglas in the mid-1970s, later joined by British Aerospace as a subcontractor. The first USMC AV-8B operational squadron was commissioned on 30 January 1985 and the first of an initial sixty GR.5s was delivered to the RAF on 1 July 1987. Even before these improved Harriers became operational, there was a growing interest in both countries in developing an advanced, supersonic replacement.[5]

Given the previous government and industry co-operation on the Harrier and Harrier II, further collaboration on the next generation of STOVL fighters seemed logical:

> Collaboration offers the benefits of cross-fertilization of ideas, economy in research resources, including facilities, sharing of development costs, and economies in production costs arising from increased production runs. In the case of STOVL, both the U.S. and the UK have substantial industrial bases from past and current R&D (research & development) programs, a common background of service experience and, potentially, much commonality of interest in the future use of advanced STOVL aircraft.[6]

A five-year MOU was signed in January 1986, providing for the balanced exchange of relevant information between the two governments, free of payment. The largely separate efforts within each country took place under the overall direction of a joint program management structure. This framework was acceptable for the early stages of the program, which consisted primarily of studies and component technology work.[7]

The program received a boost from the Nunn-Quayle Research & Development Initiative, passed by the U.S. Congress in 1987, specifically for the purpose of encouraging and supporting international cooperation in defense programs. This brought DARPA into the program, and changed the program focus from technology work and component development to flight demonstration.

The original five-year MOU expired in 1991. While the provisions of that MOU no longer applied, industry and government officials continued to coordinate activities in the two countries as much as possible, and worked to develop a framework for cooperation in the coming phases of the program. A Risk Reduction/Critical Technology Validation phase, referred to as Phase II, was planned for 1993-96, in which two competing contractor/teams would perform design analysis, component and subscale model testing, and Large Scale Powered Model (LSPM) testing. This would be followed by the selection of a single team to build two full-scale flying demonstrator aircraft, one CTOL and one STOVL, for flight tests in 1999 or 2000.[8]

Other changes by this time had complicated the prospects of continued international collaboration. It had become clear that any future STOVL strike fighter would have to include low observables. In addition, derivatives of the U.S. Air Force Advanced Tactical Fighter engines (the Pratt & Whitney F119 or the General Electric YF120) had emerged as the most likely powerplants. The U.S. closely protects low observable and advanced engine core technologies, and for a time it was not certain whether it would be possible to continue collaboration with the UK in the ASTOVL Program.

A decision was made to proceed with the program while these issues were being worked out. Accordingly, the contracts for Phase II were awarded in March 1993. A new MOU, covering UK participation in the Risk Reduction phase, was subsequently signed in August 1994. Under the new MOU, the UK provided $12 million in direct payment plus intellectual property (work in kind, use of test facilities, etc.) for a total of 35% (or roughly $25 million) of the ASTOVL Phase II Program cost. With the signing of the MOU, a Royal Navy Deputy, Commander Phil Hunt, was assigned to DARPA's ASTOVL Program Office.

Thus, the ASTOVL Program was roughly half way through its Risk Reduction phase, and an agreement with the UK was in place, when the program became part of JAST in October 1994 by the direction of the U.S. Congress. The ASTOVL MOU was transferred to JAST until a permanent JAST agreement could be developed and staffed. Commander Hunt became the first foreign national assigned to the JAST Program Office when the ASTOVL program office staff relocated to the JSF Program Office in early 1995.

9.2.4 Development of the JSF International Program Framework

While the integration with ASTOVL was taking place, JAST personnel were just beginning to work out the details of how to organize international participation. CAPT Simeon Austin (NAVAIR Liaison), CAPT [redacted] (Deputy Director, Program Integration & Analysis) and [redacted] (the recent ASTOVL Program Manager) led this effort. By the end of 1994, a preliminary plan was defined and Maj Gen Muellner briefed it to [redacted] then USD(A&T). General Muellner's briefing included several basic tenets of international cooperation drawn from the experiences of the F-16 Multi-National

Fighter Program (MNFP), foremost of which was that any participant must bring funding. However, there were also important departures from the F-16 approach. In particular, JAST did not intend to offer any offsets (e.g., guaranteed work shares, allocated in proportion to the number of production units each participating country planned to purchase). It was JAST Program philosophy not to dictate design solutions or other decisions to the WSCs. So, any foreign industry participation would have to "earn its way" into the program by offering the "best value" to the JSF Program Office or to the prime contractors in the program.[9]

Beyond the established principles of the MNFP, General Muellner's briefing addressed two other important issues. The first was when JAST could accept an influx of new thoughts and influences. These windows defined the possible "on-ramps" into the program for international partners. The second issue concerned the "off-ramps": when and how an international partner might leave the JAST Program without disrupting the program or creating a security risk.[10]

The basic concept was as follows. Depending on the nature of a given country's interest in the program, a specific task or project would be "carved out" and an MOU drawn up defining the country's participation in that project. The timing of such projects would generally coincide with major program phases (because of the time required to get an MOU approved, it would not be practical to define projects of shorter duration). As a project neared completion, the partner could either stop there, or pursue continued participation into the next phase.

[redacted] commended the proposed framework, as did Dr. John Deutch, then Deputy Secretary of Defense and [redacted] immediate superior. Dr. Deutch noted that he had seen several good models for "on-ramps," but this was the first time he had seen the issue of "off-ramps" seriously and credibly addressed. The result was that OSD not only approved JAST's concept, but also considered it a model for future international collaboration.

While the August 1994 U.S./UK ASTOVL MOU carried over to JAST (upon the ASTOVL merger into JAST), by early 1995 JAST was already looking beyond that MOU to include the UK in the forthcoming CDP. By this time, however, a major change was taking place. JAST was not initially a formal weapons system acquisition program, but was intended to lay the groundwork for future acquisition programs. It was recognized early on that a single family of CTOL, CV, and STOVL variants was feasible, and that it represented the most affordable solution to the services' next-generation strike requirements. JAST therefore evolved into an acquisition program centered around just such a family.

The STOVL member of this family would meet the needs of the UK's RN. However, the FOA constituency within the RAF lost interest in JAST. They envisioned a larger, twin-engine, "high-end" aircraft, while JAST—particularly with the STOVL influence—was evolving towards smaller, lightweight, single-seat and single-engine. Thus, the RN rather than the RAF became the focal point for UK interest in JAST.

With the existing ASTOVL MOU as a baseline, officials worked to define what both countries wanted in a new MOU. In addition to the JAST personnel noted above, [redacted] (a lawyer with the Navy International Program Office [NIPO]) and [redacted] (Lead Negotiator, also with NIPO) were key participants in this process. The first set of preliminary technical discussions took place on 24 March 1995. Three sets of negotiations followed (in the UK and U.S.) between 22 May and 24 August 1995, before the MOU was sent to OSD.[11]

An International Programs Office was established within JAST in late 1995, with [redacted] as its first Director [redacted] replaced him as Director of the International Program Office in August 1996). In December of 1995, the UK signed a new MOU as a full collaborative partner in the JAST Program for CDP and will contribute $200 million and substantial intellectual property to the overall effort.[12]

The process developed for British participation was then used as a framework for other countries wishing to participate in the JAST Program. When the WSCs learned that JAST had an approved framework

for international participation, they began to actively promote the program abroad thereby stimulating greater international interest. The first formal JAST/JSF briefing to prospective international partners was presented by Rear Admiral Craig Steidle to the F-16 MNFP countries of Belgium, Denmark, the Netherlands and Norway. By early 1996, Canada, France, Germany, Italy, Spain and Sweden had received similar briefings. And, by the end of 1999, Denmark, the Netherlands, Norway, Canada, and Italy, had become partners, while Singapore, Turkey, and Israel were FMS customers; Australia, Portugal, and Switzerland had also received briefings on the program. The following section describes the structure that was developed for international participation in the JSF Program.

9.3 Current Structure

9.3.1 Overview

There are four levels of participation in the CDP JSF Program, and that participation is governed by their MOA/MOU[*] or Letter of Offer and Acceptance (LOA). These levels are shown below:

I. Full Collaborative Partner
   A. Full partners within an MOA/MOU framework with the ability to influence requirements.

II. Associate Partner
   A. Limited partner within an MOA/MOU framework.
   B. Limited participation in specific technologies or core program with limited ability to influence requirements (where mutually beneficial to U.S. and all partners).
   C. Allowed access to JSF Program information in order to better understand and evaluate the utility of the JSF family of aircraft for their use, and to factor it into their defense planning.

III. Informed Partner
   A. Allowed access to JSF Program information in order to better understand and evaluate the utility of the JSF family of aircraft for their use, and to factor it into their defense planning.
   B. No influence on requirements.

IV. Major Participant
   A. Country participates as a Foreign Military Sales (FMS) customer through an LOA.
   B. Provides the major participant insight through JSF studies, technical assistance and access to predetermined data.

Initially, the fourth category was “Fee-for-Service”, where the foreign industry was to provide technical expertise or contributions in exchange for payment; the relationship was intended to encourage the use of subcontractors to the U.S. primes from those countries. However, the desires of candidate countries created the need for a Major Participant category in 1999. These countries are not truly Partners, but are merely purchasing services or information from the JSFPO for a fee. FMS participation does not allow a Program Office presence, nor participation in Program Office activities beyond what the nation specifically purchased.

To safeguard a participating nation’s classified and industry proprietary information, the program office establishes a unique and different project for each participating country. This also ensures equitability, both in the sense that the United States is being fairly compensated and the U.S. is not overcharging participating nations. However, countries may also choose to team together on a project.

The UK, having contributed $200 million and intellectual property largely related to the development, production and operation of the Harrier and Sea Harrier, along with subsequent ASTOVL R&D activities,

[*] The JSF Program office does not distinguish between a Memorandum of Agreement and a Memorandum of Understanding, but other countries do, so the JSFPO uses whichever term fits a particular nation’s needs.

is the only Full Collaborative Partner in the JSF Program. The RN plans to replace its Sea Harriers with the JSF, and the RAF will consider JSF as a replacement for its GR.7 Harrier. Denmark, the Netherlands and Norway are participating together (as a team) as Associate Partners, with Italy and Canada as Informed Partners, all for contributions of $10 M each. Israel, Singapore and Turkey are all Major Participants but each is structured differently. The Major Participants chose from a list of possible FMS specific projects, with Israel choosing projects worth $0.75 M, Singapore $3.6 M and Turkey $6.2 M.

9.3.2 Procedural Aspects

The JSF International Program Office provides briefings to interested nations upon request. Following the initial briefing, if the nation continues to show interest in joining the JSF Program, it is the responsibility of that country's Defense Ministry or equivalent to inform the U.S. USD(AT&L), stating interest and requesting technical discussions preliminary to formal negotiations. The JSF International Program Office then holds at least one technical discussion with the requesting country to clarify expectations, objectives, the scope of project work, and the financial and non-financial contributions expected. When technical discussions are concluded, the JSF International Program Office submits a Summary Statement of Intent (SSOI), laying out the results of the technical discussions and any potential security problems that may arise, to the OSD for approval. The OSD reviews the SSOI and gives the International Program Office the authority to negotiate a Memorandum. When negotiations are complete, a draft Memorandum goes through national staffing. After approval of the SSOI by OSD, it usually requires approximately one year for the Memorandum to be signed. Following this, a letter is forwarded to Congress, notifying it of a proposed government-to-government relationship concerning the Joint Strike Fighter. Congress then has thirty days to consider that relationship. This Congressional notification is required by Section 27 of the Arms Export Control Act. If Congress does not object, within thirty days, the relationship is automatically approved (all such JSF agreements to date have been approved). An identical procedure to that above will be used to integrate international partners into the EMD phase of the program.

Payment by member nations is made directly to the Joint Strike Fighter Program, under terms set by the Financial Policies and Procedures Document (FPPD) attached to each Memorandum. The FPPD covers issues such as payment schedules and financial arrangements. The joining nation usually selects an American bank with which it has an ongoing relationship. This streamlined financial procedure, used in the past only for special projects, provides for clear accounting and rapid transfer of funds.

Attaching the FPPD to the Memorandum (rather than making it integral to the Memorandum) means the Memorandum does not need to be amended to make changes to the FPPD. Rather, any necessary changes can be made to the FPPD by the Executive Committee (EC).

The EC is unique to each national project. As an example, in the case of Denmark, the Netherlands, and Norway, it consists of the following representatives or their equivalents in the event of reorganization:

- The Royal Danish Air Force Technical Director
- The Royal Netherlands Air Force Deputy Director of Materiel for Plans and Projects
- The Royal Norwegian Air Force Materiel Command Deputy Commander
- The Joint Strike Fighter Program Director

The JSF Program Director has management responsibility for the Program. The Program Director is represented in routine international matters by the JSF Director for International Affairs. A National Deputy from each partner country is assigned to the JSF International Program Office (which is close to, but not co-located with, the JSF Program Office).

The EC meets semi-annually, or more often if all the representatives agree. The meetings are chaired by the host country participant, a responsibility that alternates among participants. The EC's responsibilities include broad, executive-level oversight of project efforts, including making decisions and reviewing

progress. The EC maintains financial oversight, reviews plans for future JSF cooperation, and promptly appraises any issues brought to its attention by the JSF Director for International Affairs. The EC also monitors third party sales and transfers, oversees the security aspects of the project and, when appropriate, recommends, reviews and forwards for approval by the participants, the admission of other interested nations to the project.

By far the largest portion of a JSF Memorandum negotiated with any given country is dedicated to security, including such issues as disclosure and use of project information, controlled unclassified information, visits to establishments, third party sales and transfers, and participation of additional nations. Each nation's classified information must be protected, as well as each company's proprietary information. At the same time, not only is the program in a competitive phase between two weapons system prime contractors, but also three countries (besides the two full collaborative partners) are validating their requirements and a fourth is focusing on engineering and technological issues. The U.S. is determined both to protect its own sensitive technologies and at the same time deal honestly with its allies. Achieving the proper balance between protection and cooperation is an ongoing challenge.

9.4 Overview of International Participation

In the post-Cold War environment, international participation has become part of the DoD's stated strategy for affordably fielding the best possible weapons systems, while continuing to support the required force structure and readiness levels.[13] To guide international involvement in the JSF Program, the Program Office has developed an innovative four-level structure, which permits interested foreign governments to participate in specific projects, to which they must provide an appropriate level of funding and intellectual investment.

Foreign participants could benefit by receiving the end product—the JSF—at a lower cost, and more closely tailored to their needs. End item sales, however, will be decided on a case-by-case basis once the JSF enters its production phase. Participation in the JSF Program also facilitates dialogue and improves the prospects for a country's industry and defense research and development establishment to become involved in the JSF Program. The JSF Program sponsors industry cooperation events in each interested country to introduce that country's contractors to American contractors working on the JSF. However, this is less concrete than the traditional system of offsets, or guaranteed work shares, which nations customarily receive in exchange for their participation and financial support. To gain JSF-related business, foreign companies must earn their way into the program by showing a competitive advantage in terms of the quality and/or price of their products or services.[14, 15]

This concept of allowing foreign industrial participation based on competition, rather than negotiated work shares, is intended to keep down the development and production costs of the JSF. But this also introduces potential political and economic obstacles from the point of view of prospective foreign participants. Foreign governments must weigh the benefits of participation in the JSF Program against such political and economic factors as national pride, defense jobs and the defense industrial base in their own country, and perceptions of one-way defense trade with the U.S.[16] This is tempered by the fact that foreign industry can get involved in the JSF program if they have a competitive product to offer and their chances of getting involved are enhanced if there are government-to-government agreements (i.e., MOU/MOA/LOA) in place.

Other challenges, particularly when compared with the F-16 MNFP Program, include the fact that the JSF Program is in a competitive phase (whereas international participation in the F-16 program proceeded after General Dynamics won the Lightweight Fighter/Air Combat Fighter competition). Also, the JSF will incorporate many more sensitive technologies than did the F-16. These issues have resulted in some disconnects between the expectations of foreign participants, and the way the agreements were actually implemented. While the development of the program's MOUs generally proceeded very well, in retrospect

it would have been better to spend more time upfront understanding disclosure constraints dictated by National Security Policy and how those constraints impacted the day-to-day implementation of the MOUs.[17]

During 1999, the JSF International Directorate began a successful move towards an approved EMD International Business and Arms Transfer Policy. After a year of internally developing this strategy, the first successful hurdle was overcome with the Arms Transfer Policy Review Group (ATPRG) approval of the plan in April 1999. The ATPRG is a top level DoD organization recently created by Dr. Gansler, USD(AT&L), for projects such as JSF that are attempting to integrate foreign participation into the Program Office. At this point it became necessary to begin coordination with the State Department, which submitted its approval in October 1999 along with the Commerce Department. The International Directorate has also satisfied inquiries of both the House and the Senate.

While EMD will simplify matters somewhat by eliminating the need to separately protect the proprietary information of competing prime contractors, other issues will remain. These include: 1) the protection of contractor proprietary information from improper disclosure outside the program; 2) protection of classified and controlled unclassified information of each participating government; 3) physical integration of international partners into the program office; 4) technology transfer between the U.S. and its allies; and, 5) decisions as to the nature and extent of Foreign Military Sales of the JSF. Because JSF is a pilot program for international cooperation in major, advanced weapons system development, these issues must be resolved satisfactorily to provide a future precedent. Achieving the right balance between collective and national security will remain a permanent challenge in the ever more closely integrated world of defense acquisition.

Another significant preparation event was the JSF International Day in October 1999. This was a gathering of the entire JSF international team including the JSFPO, prime contractors, SAF/IA, Navy IPO, and Offices of Defense Cooperation (ODCs) from the present partner and FMS countries. Information was exchanged and policies and strategies were established and clarified for the future of the program.

In preparation for the numerous countries expected to be interested in EMD participation, the JSFPO completed its internal production of a draft MOA for the new phase, and discussions have begun with the current partners regarding their position during EMD. The JSFPO has also been providing briefings to countries that are officially expressing interest. In July 1999, the Swiss Air Force Chief of Staff received information on EMD; in December the Australians received a briefing. Poland, Germany, Greece, Japan, and Kuwait have also received information on possible involvement with the program.

In November 1999, Dr. Gansler's office sent out the formal invitations to participate in EMD to the present CDP partners. The Program Office began receiving replies the same month. Formal negotiations regarding EMD began with the UK in November 1999 and concluded in January 2001 with the signature of the first JSF EMD formal international partnership. Negotiations with the Dutch, Italians, Turks, Canadians and Denmark/Norway (together) are continuing.

9.4.1 United Kingdom

As of the end of 1999, the MOU between the Secretary of State for Defense of the United Kingdom and the U.S. Department of Defense has been in effect for five years; the MOU was amended in January 1999 to include the Royal Air Force. The stated objectives of this MOU are to harmonize the requirements of the British services and the U.S. services as well as to conduct specific joint projects relating to the STOVL version of the JSF.

Besides these specific projects, the UK maintains a constant and working level presence in the JSFPO. Most significantly, UK military personnel are seamlessly integrated into the Program Office and conduct important work on both UK and non-UK related issues. UK personnel function almost as US personnel in many ways, fully integrated into several of the IPTs. This integration and cooperation has been vastly

important in modeling future participation in the JSF program. As a Full Partner, the UK is permitted a National Deputy at the Director level, as well as eight country representatives. Captain [redacted] began his tenure as UK National Deputy in the Program Office in 1999, replacing Captain [redacted] in January. Two UK EC meetings were held in 1999; the first was held in April in Crystal City, Arlington, Virginia. The second meeting was conducted in October by Program Office members and representatives of the UK in Seattle, Washington.

The JSF Vectored-Thrust Aircraft Advanced Flight Control (VAAC) Follow-On Research Program conducted flight testing in October 2000 in the UK. This was a joint US/UK/Italian sponsored program to investigate advanced control law strategies for STOVL flight operations. The research results will help reduce the risk of the JSF STOVL flight control system development efforts as the program enters into EMD. The VAAC flight test program included 30 flight hours, split between land based and shipboard flight test evaluations. Flight tests continued through December 2000, culminating in the final shipboard evaluations aboard the HMS Invincible.[18]

In 2000, a single EC meeting was held in London during April. Most significantly, the United Kingdom signed both the Core MOU for international participation as well as their UK specific supplemental MOU in January 2001. The UK will participate in source selection activities and be on board from the first day of EMD.

9.4.2 Denmark, Netherlands & Norway (DNN)

Denmark, The Netherlands, and Norway entered into negotiations together for a single MOA during 1996. The Netherlands and Norway signed the MOA on 16 April 1997 and Denmark signed an MOU on 10 September 1997. Each contributed $10 million to participate together as Associate Partners under the Requirements Validation Project to develop a mutually beneficial set of JSF CTOL variant requirements for use in their national decision making process regarding the JSF. Their combined contribution is matched by the U.S. for a total Project value of $60 million. As Associate Partners, Denmark, The Netherlands and Norway have the ability to influence requirements provided the proposed requirements modifications are mutually beneficial. They are also permitted one National Deputy per country, and one technical representative for the group. Colonel [redacted] the Danish National Deputy, joined the Program Office in September 1997, and Colonel [redacted] the Norwegian National Deputy, joined in April 1997. Colonel [redacted] replaced Colonel [redacted] the former Dutch National Deputy in May 1999.

Denmark, The Netherlands, and Norway have taken part in numerous events and received many documents over the past two years. Pilots from the partner nations have taken part in VSWEs as well as FMS events. The three countries were also involved in the JSF System Threat Working Group. In addition, The Netherlands, through its RFI process, is continuing to gather information for later government decisions on its involvement in JSF EMD. As part of the many visitors to the JSF Program Office, Air Commodore Vorderman, Dutch JSF Program Manager; LTGEN Droste, Dutch Air Force Chief of Staff; MAJGEN Jacobsen, Norwegian Air Force Chief of Staff; [redacted] Norwegian Armaments Director; [redacted] Dutch Defense Secretary; [redacted] Dutch Armaments Director; and [redacted] Danish Agency for Trade and Industry; have all visited for meetings with the JSF Directors. In May 1999, Program Office members and representatives of the partner countries traveled to Oslo, Norway for EC meeting #4. In November 1999, Program Office members and representatives of the partner countries traveled to The Netherlands for the final EC meeting of the year.

Two EC meetings took place during 2000: one in February that was located in Los Angeles to allow viewing of the aircraft at Palmdale; and one in October in Copenhagen, Denmark. EMD negotiations continue into 2001. As opposed to the single "DNN" MOU in CDP, negotiations currently revolve around The Netherlands as a single partner and Denmark/Norway as a entity.

9.4.3 Canada

Canada signed an MOU with the United States on 2 January 1998 to participate in the JSF Program as an Informed Partner in the PWSC Refinement Project. The PWSC Refinement Project focuses on design refinements, integration of leveraging technologies, and associated engineering for the JSF CTOL variant. Canada is contributing $10 million to this refinement Project, and the U.S. $50 million. As an Informed Partner, Canada does not have the ability to influence requirements.

The stated objectives of this MOU are to conduct cooperative CTOL PWSC refinement efforts focusing on design refinements, integration of leveraging technologies and associated engineering efforts. In addition, the MOU provides for promoting industrial research and development opportunities and allowing Canada the information needed for their national decision process regarding the future of JSF. [redacted] the Canadian National Deputy, joined the JSFPO in January 1998.

Canada has taken part in numerous events and received much information over the past two years. Canadian service members have also taken part in Program Office sponsored VSWE and FMS events. A JSF System Threat Working Group also involved the Canadians.

In February and October 1999, Program Office members and representatives of Canada participated in EC meetings; EMD participation as well as present efforts were discussed. The 3rd EC meeting in October was the first for [redacted] Canada's new Director General, International & Industry Programs. During 2000, a single EC meeting was held, during October.

9.4.4 Italy

Italy signed a MOA with the United States on 23 December 1998 to participate in the JSF Program as an Informed Partner. The Italian Air Force is considering purchasing the CTOL version while the Italian Navy is looking at the STOVL version. The stated objectives of this MOA are to perform mutually beneficial STOVL ship integration risk mitigation and CTOL/STOVL operational assessment tasks as well as facilitate industry contacts and to provide the Italians with project information in order to facilitate their national decision making process.

Italy has taken part in numerous events and received many documents over the past year. Pilots from the Italy have taken part in VSWE and FMS events, and Italy was also involved with the JSF System Threat Working Group. Italian funding goes towards the above mentioned risk mitigation studies and other related projects.

In May 1999, Colonel Stephano Salamida came aboard at the Program Office as the Italian National Deputy. In November 1999, Program Office members and representatives of Italy conducted their first EC meeting in Washington, DC. During 2000, a single EC Meeting occurred in June in Rome.

9.4.5 Singapore

The Ministry of Defense of Singapore signed as a FMS Major Participant to the JSF Program on 20 March 1999. The Letter of Offer & Acceptance (LOA) brought the Singaporeans into the Generic JSF project, which is an effort to describe the JSF aircraft in non-classified, non-proprietary terms. Singapore also participated in the "Joint Strike Fighter Makes A Difference" campaign model simulation. This simulation uses the COMBAT IV military campaign model loaded with information specific to each country, and run with a legacy force (F-16s) and with the JSF to show the differences in a given campaign. They also participated in PWSC Program Management Reviews, the receipt of the Program's primary Requirements Documentation, and training in the Program's COPT process.

Planning meetings have begun in both the U.S. and Singapore for a number of projects. In early December 1999, Program Office personnel left for Singapore to conduct the weeklong COPT training

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session. Several requirements documents have already been supplied to Singapore. In addition, the first Project Review was held to look at the financial and programmatic status of the Project. General Ng, Singapore Air Force Chief of Staff, visited the JSFPO in September 1999 for a meeting and discussion with Brigadier General Hudson. During 2000, JSF Modeling and Simulation Events occurred in Singapore as well as Program Management Reviews with both contractors. Most events outlined to occur in the LOA have occurred and activity with Singapore is beginning to come to a close.

9.4.6 Turkey

The Ministry of National Defense of Turkey signed on to the JSF Program as a FMS Major Participant on 16 June 1999. The LOA brought the Turks into the Generic JSF project. They also signed up for PWSC Program Management Reviews, the “Joint Strike Fighter Makes A Difference” model simulation, the receipt of the Program’s primary requirements documentation, and training in the Program’s COPT process. In addition, both an air-to-air and air-to-ground virtual Early Operational Assessment have taken place using U.S. programs and equipment and Turkish pilots.

Planning meetings have begun in both the U.S. and Ankara, Turkey for all of these projects. Specifically, PMRs have taken place with the contractors, and in early September 1999, members of the Program Office left for Turkey to conduct a weeklong “Joint Strike Fighter Makes a Difference” orientation. Most requirements documents have already been supplied to Turkey. In October, Program Office personnel traveled to Turkey to conduct a site survey of the F-16 logistical system with an eye toward changes and updates to support the JSF. In addition, the first Project Review was held to look at the financial and programmatic status of their program.

During 2000, modeling and simulation events took place in Turkey as well as at WPAFB and Pax River. Most events outlined in the LOA have occurred and activities with Turkey are beginning to diminish. Negotiations for EMD, however, continue.

9.4.7 Israel

The Israeli Ministry of Defense signed on to the JSF Program as a FMS Major Participant on 23 September 1999. The LOA brought the Israelis into the Generic JSF project. The Israelis hosted a JSF Industry Day in Tel Aviv on 9-11 November, involving the JSFPO, the WSCs, the engine contractors and Israeli Industry. These two projects were provided for $0.75M. The Israeli LOA will end in mid-2001.

9.5 Summary

The JSF Program currently includes six foreign Partners and three Major Participants at various levels of participation (see Table 29, below). Additional foreign governments may eventually join the program and/or procure the JSF to meet their future tactical aircraft requirements. Negotiations are now being conducted to conclude agreements with the JSF partners and other countries for the EMD Phase. Each of the countries is being provided with important JSF information (according to their level of participation) and visibility into the evolving concepts. JSF’s international collaboration is considered a model for future programs with international participation.

Table 29: Summary of JSF International Participation

Country	Type of Membership	Type of Agreement	Financial Contribution	US Contribution	Date Joined
United Kingdom	Full Collaborative Partner	MOU	$200 M	-	Dec-95
Netherlands	Associate Partner	MOA	$10 M	$10 M	16-Apr-97

Norway	Associate Partner	MOA	$10 M	$10 M	17-Apr-97
Denmark	Associate Partner	MOU	$10 M	$10 M	10-Sep-97
Canada	Informed Partner	MOU	$10 M	$50 M	02-Jan-98
Italy	Informed Partner	MOA	$10 M	-	23-Dec-98
Singapore	Major Participant	LOA	$3.6 M	-	20-Mar-99
Turkey	Major Participant	LOA	$6.2 M	-	16-Jun-99
Israel	Major Participant	LOA	$0.75 M	-	23-Sep-99

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1 *International Programs Security Handbook*, Office of the Deputy to the Under Secretary of Defense (Policy) for Policy Support, Richmond, VA, February, 1995, rev. ed., June, 1996, pp. 1-2.

2 JAST Transition Planning Team, "Brig Gen Muellner's Comments During 18 Nov Investment Planning Briefing," November 1993.

3 *Report of the Defense Science Board Task Force on Joint Advanced Strike Technology Program*, Office of the Undersecretary of Defense for Acquisition & Technology, Washington, DC, September 1994, p. ES-7.

4 *STOVL 2000 Executive Steering Committee, Meeting 026 Minutes*, Bristol, England, 29 June 1994.

5 *Jane's All the World's Aircraft,* 1988-9 edition, Jane's Information Group Limited, Coulsden, Surrey, U.K., p. 125.

6 [redacted]

7 [redacted] *Overview of the U.S./U.K. ASTOVL Program*, Paper #872365, SAE International Powered Lift Conference & Exposition, Santa Clara, CA, 7-10 December 1987.

8 *STOVL 2000 Executive Steering Committee*, *Meeting 013 Minutes*, Epcot Center, Orlando, FL, 27 March 1991, and *Meeting 018 Minutes*, Buckingham Gate, United Kingdom, 23 June 1992.

9 Muellner, George K., Lt Gen USAF, Interviewed by [redacted] 22 and 28 January 1998.

10 *Ibid.*

11 [redacted] CAPT USN, interviewed by [redacted] 26 January 1998.

12 [redacted] JSF International Programs Director, Interviewed by [redacted] 18 January 1998.

13 [redacted], Under Secretary of Defense (Acquisition & Technology), "*The Defense Acquisition Challenge: Technological Supremacy at an Affordable Cost*," Presented at the National Security Industrial Association JAST Industry Conference, 31 January 1995.

14 [redacted] 1998.

15 Kenne, Leslie F., M Gen USAF, JSF Program Director, Interviewed by [redacted] 22 April 1998.

16 [redacted] Lt Col USAF, Deputy Program Director for Airborne Laser (formerly JAST Avionics IPT Lead), Letter to [redacted] and [redacted] with attached comments, 12 April 1998.

17 [redacted] 1998.

18 "Weekly Activity Report," 21-27 October 2000.

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10 Summary

The JSF Program has progressed very rapidly through preliminary stages and entered CDP (corresponding to Phase I in the DoD 5000 acquisition model) just three years after the program was initiated. This was due to a combination of "requirements pull" (i.e., a recognized, urgent need, though there was no requirement in the formal sense), and a strong, top-level "push" to execute necessary tasks in a streamlined manner.

Traditionally, a Mission Needs Statement (MNS) has been required prior to Milestone 0, and ORD prior to Milestone I of an acquisition program. The development and validation of these documents required that the operational and acquisition communities and senior leadership of the service(s) come to an agreement, first on the need for a new weapons system, and then on what the general characteristics of that system should be. The necessary concept studies, technology studies, mission analyses and related activities often took years, and tended to determine system important characteristics—including cost—before the program even got started.

The JAST Program did not initially have a formal, validated requirement, but only a broadly defined need, to replace aging strike aircraft in the 2010 timeframe. JAST was started on the basis of that general need. The approach of determining specific requirements in parallel with the early stages of the program, rather than waiting for the requirement before starting the program was and is both new and innovative. The urgency of the need contributed to a willingness on the part of the participating services to both work together and to try something new.

The informal first phase, Concept Exploration (1994), identified the concept of a highly common "family of aircraft" as the most affordable solution to the needs of the participating services, and identified opportunities for cost savings through the use of advanced technologies or improved processes. The second phase, Concept Definition & Design Research (1995-6), developed specific weapons system designs based on this concept. Technology needs were identified, and Tech Mat and CDP plans were developed. The Tech Mat strategy was refined through several iterations, with input from the warfighters and from the weapon system contractor design teams. Preliminary requirements and cost targets were also identified, but much more importantly, the COPT process got underway. This process provides the framework through which the services' requirements communities interact and develop affordable, achievable joint service requirements. CDP is structured to execute the plans developed in the previous phases, to support a Milestone II decision in 2001 for the start of EMD.

During its activities to date, the JSF Program pioneered many new ways of accomplishing weapons system acquisition. At the onset of CDP, the top leaders of the JSF Program Office were asked what some of the greatest challenges would be. The general consensus resulted in these areas:[1, 2, 3, 4, 5]

Keeping the program focused on affordability. This has been the primary emphasis in the program from its inception through the beginning of CDP. It will be important to maintain this affordability focus as the JIRD becomes the JORD, and not to revert to a "performance at any cost" mindset as the final requirements decisions are made. Similarly, the contractors must continue to make affordability co-equal with performance, and not fall back into past business practices, where the performance goals were almost always met, but often at the expense of exceeding the cost goals.

Demonstrating the viability of the "family of aircraft" concept. This is a major technical challenge. The CDA flight demonstrations will be a critical step in proving the feasibility of this concept.

Transitioning the selected technologies and realizing the associated cost savings. While the Tech Mat activities may not be as high profile as the CDA flight tests, they are essential to making the production JSF weapon system capable, affordable, and sustainable.

Maintaining the momentum of "doing business differently" to control costs in the EMD and subsequent phases. It is also important to remember that "doing business differently" is a means to an end and not an

end in itself. Acquisition processes should "buy their way" into the program just as new technologies "buy their way" onto the aircraft—by demonstrating real value added and real cost savings.[6, 7]

The biggest single obstacle in many of these areas has been *acceptance*. The JAST Program was chartered to pioneer acquisition reform and streamlining, and that is still an important part of the JSF Vision. However, to do business differently it is necessary to gain acceptance at all levels – the working level, senior leadership, and a variety of outside agencies. The JSF Program has, on the whole, been very successful in this area, but acceptance of new and innovative practices will continue to be a challenge, particularly as the funding levels of the program must necessarily rise.

There are two extraordinary weapon system contractor teams working with the JSF Program Office to meet the technical challenges that lie ahead, and the Program Office has established exemplary relationships with them. The contractors openly share data and issues with the Program Office practically on a real-time basis. This is the right way to do business. Similarly, the participating services are working together in an exemplary manner on all aspects of the program. International interest has increased dramatically. Program stability and Congressional, service and DoD support are currently strong.[8] The JSF Program Office is committed to working with the contractor teams and the services' requirements communities to achieve success in CDP, and ultimately to provide an affordable, sustainable family of strike weapons systems for all participants.

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1 Kenne, Leslie F., Brig Gen USAF, JSF Program Director, Interviewed by [redacted] 22 April 1998.

2 Muellner, George K., Lt Gen USAF, Principal Deputy to the Assistant Secretary of the Air Force (Acquisition), Interviewed by [redacted] 22 and 28 January 1998.

3 Schwartz, Fred, SES USAF, JSF Program Technical Director, Interviewed by [redacted] 13 January 1998.

4 [redacted] CAPT USN, JSF X-35 Program Manager, Interviewed by [redacted] 19 December 1997.

5 [redacted] Col USAF, JSF X-32 Program Manager, Interviewed by [redacted] 3 April 1998.

6 Muellner, 1998.

7 [redacted] Col USMC, JSF Systems Engineering Director, Interviewed by [redacted] 7 April 1998.

8 Kenne, 1998.

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Appendix A: US/UK ASTOVL Programs, 1983-1994

A.1 Overview

The US/UK Advanced Short Takeoff and Vertical Landing (ASTOVL) Program began with preliminary discussions between US and UK officials in 1983. A five-year Memorandum of Understanding (MOU) was signed in January 1986, establishing a joint management structure headed by the US Department of Defense (DoD) and National Aeronautics and Space Administration (NASA), and the UK Ministry of Defense (MoD) and Royal Aeronautical Establishment (RAE). The goal of the program was to perform research, design, and testing that would lead to a proven design concept for a supersonic, single-engine STOVL strike fighter. Four powered lift concepts were selected for initial study, and preliminary assessments were performed in 1985 while the MOU negotiations were still underway. More detailed studies during 1986–87 produced no clear "winners" among the original four concepts. Revised concepts were subsequently developed, including the Shaft Driven Lift Fan (SDLF) and Gas Driven (or Gas Coupled) Lift Fan (GDLF or GCLF).[1]

In 1988, the US Congress passed the Nunn-Quayle Research & Development Initiative to fund cooperative efforts between the US and NATO allies. This provided a substantial increase in resources, making eventual flight demonstration a real possibility, and brought the US Defense Advanced Research Projects Agency (DARPA) into the program. From 1988 to 1991, additional studies were performed in each country. Concurrently, the need to consider signature reduction for improved survivability began to be recognized. The USMC, USN, and the UK RN all drafted preliminary operational requirements during this period for a STOVL strike fighter incorporating reduced signatures and varying degrees of supersonic capability—ranging from very limited supersonic dash capability, to "supercruise" performance similar to the USAF Advanced Tactical Fighter (ATF). The USN draft requirements were generally the most ambitious in this respect.

When the original MOU expired in 1991, the international program officially ended. However, the airframe and engine companies' design efforts and various government activities continued. A revised DARPA/US Navy ASTOVL Program started in early 1992 with the aim of demonstrating an affordable STOVL strike fighter with a Conventional Takeoff and Landing (CTOL) variant for possible US Air Force service. Based on the earlier study results, this program focused on the lift fan concepts (SDLF and GCLF). A Request for Proposals (RFP) was issued in August 1992 for a three-year Risk Reduction phase. Contracts were awarded in March 1993 to Lockheed for the SDLF and McDonnell Douglas (teamed with British Aerospace) for the GCLF. Boeing, with a Direct Lift (DL) concept, and Northrop, with a Lift-plus-Lift/Cruise (L+L/C) concept, subsequently joined the program under a cost-sharing contract and a no-cost contract, respectively.[2, 3, 4]

In 1993 formal negotiations with the UK were begun for a new MOU, which was signed in August 1994. The new MOU applied to the recently started Risk Reduction phase, which would culminate with Large Scale Powered Model (LSPM) ground tests in 1995–96. The plan was to then select one contractor for a flight demonstration phase, leading up to a possible engineering & manufacturing development (EMD) decision by 2000. However, in October 1994 the US Congress merged ASTOVL into the Joint Advanced Strike Technology (JAST) Program. This appendix describes the ASTOVL Program from its inception in 1983, up to the time it was absorbed by JAST. A timeline of major activities are given at the end of this appendix.

This appendix is confined to those activities that were directly, or at least closely, related to the collaborative US/UK effort, since 1983, to develop an advanced, single-engine STOVL strike fighter, primarily as a replacement for the Harrier and Sea Harrier. Many other STOVL, V/STOL and VTOL efforts,

directed at other (often more ambitious) requirements or different missions entirely, were conducted before, during, and since those that are described here.

A.2 Background: the Harrier and the Harrier II

The Harrier concept originated in the summer and fall of 1957, when the Hawker Siddeley P.1127 was designed around the new Bristol BE.53 vectored-thrust engine (which was eventually named the Pegasus). Early engine development was funded 25% by Bristol and 75% by NATO's Mutual Weapons Development Program (including substantial US funding), while the airframe was initially worked as a private venture by Hawker with some technical support from RAE. In addition, NASA built and tested one wind tunnel model and one freeflight hover and transition model, providing considerable risk reduction. With funding eventually received from the UK Ministry of Supply, five demonstrator aircraft were built and flight tested from 1960 through 1963. In 1962 the US, the UK, and the Federal Republic of Germany agreed to fund a further nine evaluation aircraft, which received the name Kestrel. After extensive testing of the Kestrels in 1965, Hawker began development of the first operational jet V/STOL airplane. The production GR.1 Harrier entered service with the UK Royal Air Force on 1 April 1969, and the US Marine Corps purchased its first Harrier AV-8As the same year.[5]

The US Congress was reluctant to fund the purchase of foreign fighter aircraft unless a significant portion of the production occurred in the United States. Consequently, in 1969 McDonnell Douglas (MDA) entered into a 15-year agreement with Hawker Siddeley Aviation (British Aerospace, or BAe, since 1977, but now BAE SYSTEMS) which granted MDA the rights to manufacture and market the Harrier in the United States. The agreement also provided for the exchange between MDA and Hawker Siddeley, of data pertaining to new V/STOL designs derived from the Harrier.

As it turned out, all of the 110 AV-8As purchased by the USMC were manufactured by Hawker Siddeley. However, while both companies conducted studies of advanced versions, it was an MDA effort that eventually led to the AV-8B Harrier II. The first YAV-8B, converted from an AV-8A, flew in November 1978. BAe joined this project under a 1981 agreement with MDA, and the same year the US and UK governments signed an MOU to cover the procurement of AV-8Bs for the RAF. The first "pilot production" AV-8Bs were delivered to the USMC in late 1983. Initial Operational Capability (IOC) with the USMC was achieved in late 1985 and with the RAF (as the GR.5) in November 1989.[6]

A larger wing with supercritical airfoils and composite construction increased the fuel capacity and the up-and-away performance of the AV-8B with little impact to the empty weight. Composites were also used in the fuselage. While the engine itself initially retained the same 21,500-lb nominal thrust rating as the late AV-8As, improved nozzle design, nozzle placement/integration and Lift Improvement Devices (LIDs) increased the usable vertical lift by several hundred pounds. In a short take off, the larger wing (with improved flaps and aileron droop) provided a further increase in lift. The combined effect of these improvements was to approximately double the range-payload capability (from a short takeoff) over the earlier Harriers. [7]

Nevertheless, the Harrier has some fundamental limitations. It is built around a centrally located turbofan engine with a bypass ratio (fan flow / core flow) of 1.3, which is unusually high for a fighter. As illustrated below, the same set of swiveling nozzles produce vertical thrust for hover, and forward thrust for wing-borne flight. The concept is simple, elegant and effective. The high bypass engine is well suited to achieving a high thrust-to-weight ratio with an acceptable exhaust "footprint," and also provides high efficiency in subsonic flight. The engine is located close to the aircraft's center of gravity, eliminating the need for extensive ductwork, augmentation devices, or additional lift engine(s) forward to provide balance in hover.

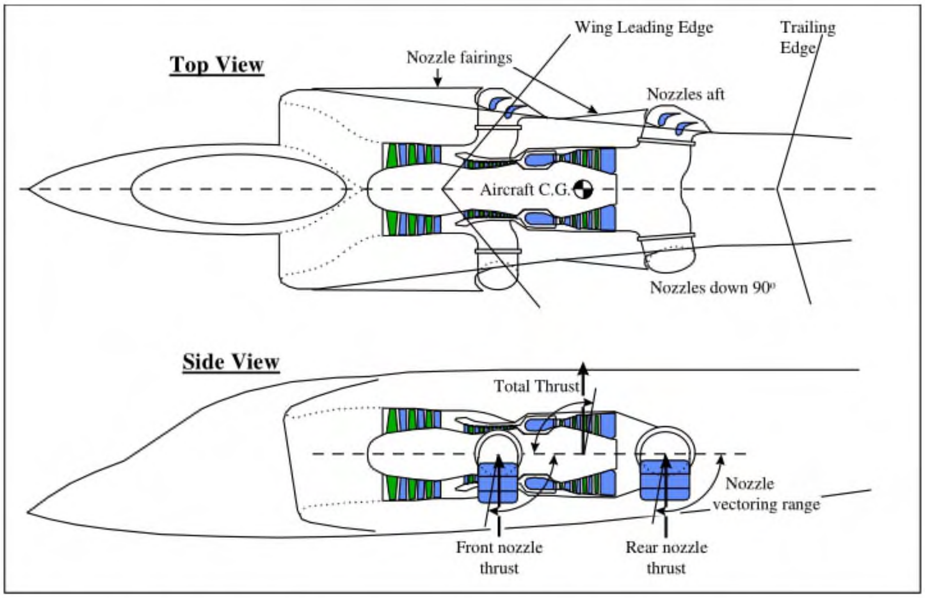
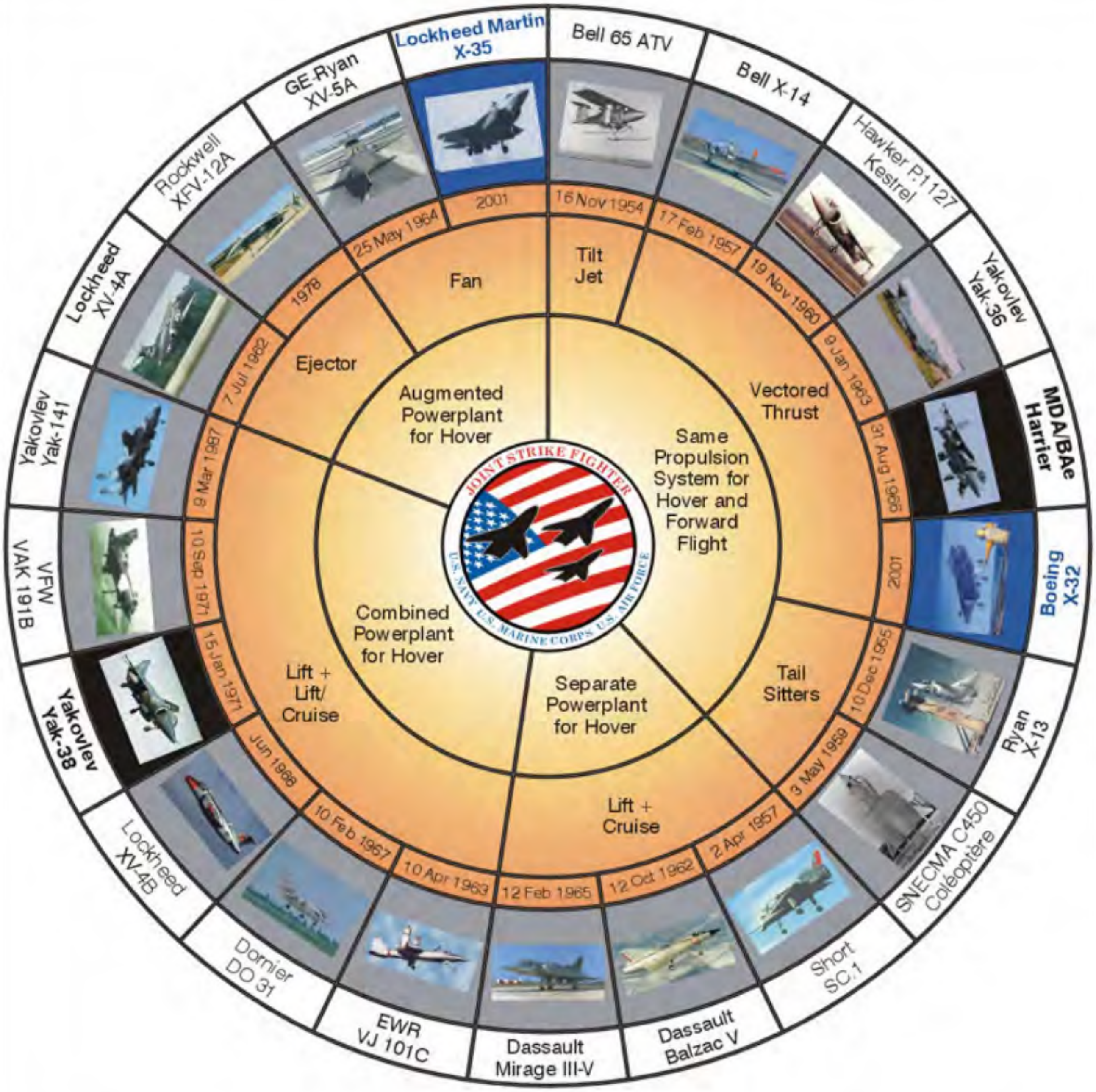


Figure 161: The Harrier's Pegasus Vectored Thrust Engine Installation[8]

However, the high bypass engine and the resultant large frontal area of the aircraft are poorly suited to supersonic operation—in fact, without afterburners (which are difficult to accommodate in the short, swiveling, centrally located nozzles), achieving useful supersonic performance with this type of propulsion installation is virtually impossible. Therefore, serious thought was given to the development of a new STOVL aircraft, with supersonic capability, shortly after the AV-8B went into pilot production.

Many other V/STOL fighter/attack aircraft were studied, and some built, during the period of the Harrier and Harrier II's development and introduction into service. The Harrier itself had been conceived as a lightweight strike / reconnaissance aircraft, although the initial impetus for the project was due to the appeal of the concept rather than to any specific mission need. However, by the 1960s, NATO had developed a pronounced interest in V/STOL aircraft that could operate from dispersed locations, as a means of making their air power less vulnerable to Soviet attacks on NATO air bases. There was particular emphasis on the nuclear strike mission, involving a low, fast dash from a forward base to deliver a single nuclear weapon. Aircraft such as the German VAK 191B and VJ 101, and the French Mirage III-V, were designed primarily for such a mission, offering some degree of supersonic dash capability but very limited performance in other respects. The US Navy was also at times interested in V/STOL aircraft, initially to replace and later, more realistically, to complement conventional carrier-based aircraft. Many design studies of naval V/STOL fighters were conducted, and the Rockwell XFV-12A was built in the 1970s but never flew successfully. None of the various concepts studied or demonstrated were as simple and practical as the Harrier, which proved to be the only Western V/STOL jet to enter service during the 20th century. A diagram of jet V/STOL aircraft types which had been built and flown is provided in Figure 162.



Depicted here are the various types of jet engine powered Vertical and/or Short Take-off and Landing (V/STOL) aircraft concepts which have been built over the past half century. So far, only two (shown in black) have led to operational aircraft. In fact, the Harrier is the only V/STOL aircraft in operation today, since the Yak-38 Forger was removed from service in 1992. The first flight dates are given for each aircraft (the XFV-12A completed only suspended tether tests), with the Joint Strike Fighter V/STOL concept demonstrator aircraft (shown in blue) scheduled to fly in 2001.

Figure 162. Jet-Powered V/STOL Aircraft Concepts

A.3 Original NASA/UK ASTOVL Program, 1983-1987

Following earlier contacts between [redacted] (Deputy Administrator of NASA, and currently DDR&E) and [redacted] (UK Minister of State, Defense Procurement), the preliminary work of formulating a cooperative US/UK program to develop an advanced Harrier replacement began at the Royal Aircraft Establishment, Farnborough, in June 1983:

> This conference, which was attended by service officers, industry personnel, government scientists and procurement officials considered the future prospects for military STOVL aircraft systems. It was concluded that an affordable future ASTOVL fighter would most probably have a single engine, with lift and cruise functions combined in the same powerplant system. Emerging technology offered the prospect of a high capability aircraft, with good agility and significant supersonic capability, with a top speed in excess of Mach 1.6. Entry into service was envisaged as in the 2000-2005 period… Substantive negotiations on the terms of the MOU commenced at a follow-up meeting of government officials at NASA Ames in February 1984, when a management structure to plan and administer the collaboration was also established… [9]

The MOU was signed in January 1986 by [redacted] (UK Chief of Defense Equipment Collaboration), [redacted] (acting Administrator of NASA), and [redacted] (US Undersecretary of Defense for Research and Engineering). The MOU did not require any direct payment from either government to the other, but instead called for a balanced exchange of relevant information, government-to-government. Each government could share such information with its industry on a need-to-know basis, although additional limitations could apply in the case of classified or company proprietary information. Activities performed by or for each government were to be funded entirely by that government, or on a shared government/industry basis. A balanced, joint management structure (described subsequently) was established to provide overall program direction. The duration of the MOU was initially set at five years, with provision for extension or earlier termination if mutually agreed to. Although the MOU did not provide for a joint experimental or demonstrator aircraft, it specifically stated that the two governments envisioned such an undertaking in the future, under separate agreements. [10]

A.3.1 Basic STOVL Design Considerations and Choice of Concepts

The program focused on a set of four propulsion/powered lift concepts which all offered some promise of matching the Harrier II's STOVL capability, while providing substantial supersonic performance. These were: Advanced Vectored Thrust (AVT), Augmentor Ejector, Remote Augmented Lift Systems (RALS), and Tandem Fan. All of these will be described below; however, the choice of concepts is best explained in light of some basic ASTOVL design considerations.

Thrust vs. weight: The most fundamental challenge in V/STOL aircraft design is that the available thrust in hover must be greater than the weight. It is not enough for the thrust to equal the weight: additional thrust margin is required for control, adverse interactions and ground effects, hot day operation, hot gas re-ingestion, and other effects. Furthermore, some maneuvers—such as an aborted landing—require a positive vertical acceleration. The available thrust, <u>after</u> all of these factors have been accounted for, must therefore be about 10% greater than the weight. For typical installations, this means that the uninstalled, rated thrust of the engine (in appropriate mode, i.e., without afterburner and allowing for any applicable power take-off) plus lift augmentation systems must usually be about 1.15 to 1.2 times the maximum weight at which jet-borne (vertical) operations will be conducted,[11] although some sources have suggested that it has to be as high as 1.3 to 1.35.[12]

This maximum vertical flight weight depends on the way the aircraft will be operated. For a Vertical Takeoff and Landing (VTOL) aircraft, all of the above considerations must apply to the aircraft at its maximum takeoff weight. If vertical takeoffs are not required, the problem becomes much easier, and this is why the preferred operating concept has evolved from VTOL to STOVL. Studies have shown that STOVL is clearly a more cost effective design approach than VTOL.[13] With a moderate takeoff roll to build up some forward speed, the aerodynamic lift generated by the wing augments the powered lift generated

by the engines, significantly increasing the allowable takeoff weight compared to a pure vertical takeoff. The requirements for vertical operation then only need to be met at the landing weight. However, this normally does include a certain amount of reserve fuel, plus an allowance for unused stores ("bring-back" load). There may also be a requirement to be able to land with an asymmetric stores load.

Nevertheless, STOVL rather than VTOL operation allows for a tremendous increase in useful load, above and beyond the maximum vertical flight weight. This translates into additional fuel (providing increased range), weapons, or a combination of the two. The takeoff run is still much shorter than that of an otherwise comparable CTOL aircraft. A STOVL fighter can be operated from US Navy L-class ships, UK Royal Navy aircraft carriers, or austere bases with runways just a few hundred feet long, as opposed to the several thousand feet required for CTOL aircraft. Furthermore, missions can typically still be performed (with reduced range and/or payload) from a pure vertical takeoff when necessary. The idea of STOVL vs. VTOL operation was first noted in the late 1950s, in connection with flight tests of the Bell X-14 vectored-thrust demonstrator. Engineers working on that project pointed out the potential to perform short takeoffs at overload weights. The idea of designing an aircraft for this type of operation (thereby relaxing several design requirements) was proposed in a US Navy technical report in 1962. Flight test experience with the Kestrel showed this to be practical.[14]

Balance: The second design challenge is maintaining longitudinal balance in vertical flight. The vertical thrust from the engine and any augmentation device(s) must be balanced about the aircraft's center of gravity (CG). On typical CTOL fighter aircraft, the engine nozzle is well aft of the CG. To achieve balance, it is therefore necessary to design a STOVL fighter with its engine unusually far forward, and/or to have a dedicated lift source in the forward part of the aircraft.

Number of engines: Some V/STOL design efforts have resorted to surprisingly large numbers of engines, in various combinations of lift engines, forward-propulsive engines, and dual-function engines, to achieve supersonic performance. Banks of two or more small lift engines, positioned in tandem, can provide the required lift with less frontal area—and therefore lower drag in supersonic flight—than a single, larger engine. Dedicated lift engines also allow the main engine to be more efficiently sized for forward flight. This is because specific fuel consumption is higher at reduced throttle settings; so it is desirable to cruise near the maximum dry thrust. If the main engine is sized to meet STOVL requirements without augmentation, it may be larger than optimum for cruise.

The disadvantage of the multi-engine approach is that lift engines add weight, cost, and complexity. Furthermore, multi-engine aircraft must normally be capable of controlled flight, at least to the extent of making an emergency landing, in the event of an engine failure. To meet this criterion in a STOVL aircraft would require:

- Sufficient thrust to hover even with one engine failed.
- Sufficient control to compensate for the thrust imbalance caused by the loss of any one engine.

Not only did this require more thrust and more control power than otherwise necessary; it tended to drive designers toward the use of **more** engines rather than fewer, so that the loss of any one would represent a smaller fraction of the total thrust. The issue was not just **"1 vs. 2"** engines, but **"1 vs. many."** Some notable examples, among aircraft that were actually built, included the VJ 101C with six engines, and the Mirage III V with nine engines (shown in Figure 162, above). Many design concepts would have used even more![15, 16]

A single-engine aircraft obviously would not be able to sustain flight if the engine failed during hover; however, the likelihood of an engine failure would be less, since the frequency of engine failures would be proportional to the number of engines. Furthermore, several studies showed that the projected life cycle cost of a fleet of single-engine STOVL fighters would be less than for a multi-engine fleet, even accounting for an increased number of losses due to engine failure. Acceptance of a single-engine solution was critical

to the pursuit of a sensible STOVL fighter design—and in fact, the Harrier itself provided a precedent. The likelihood that future engines would have improved reliability helped counter some of the remaining resistance to the idea of a single-engine, ship-based, STOVL fighter.[17, 18]

Selected Concepts: The four selected concepts are illustrated and described below. The central theme in all of these concepts was the use of some form of thrust augmentation in hover, to provide increased lifting capability without having to severely oversize the main engine relative to the cruise thrust requirements. All of the concepts were generally expected to use afterburning in forward flight to help achieve the desired supersonic performance. All of the concepts were single-engine, and all but one (Advanced Vectored Thrust) provided for a dedicated lift source forward, allowing the center of vertical thrust (and hence the aircraft's center of gravity) to be decoupled from the location of the main engine and cruise nozzle(s).

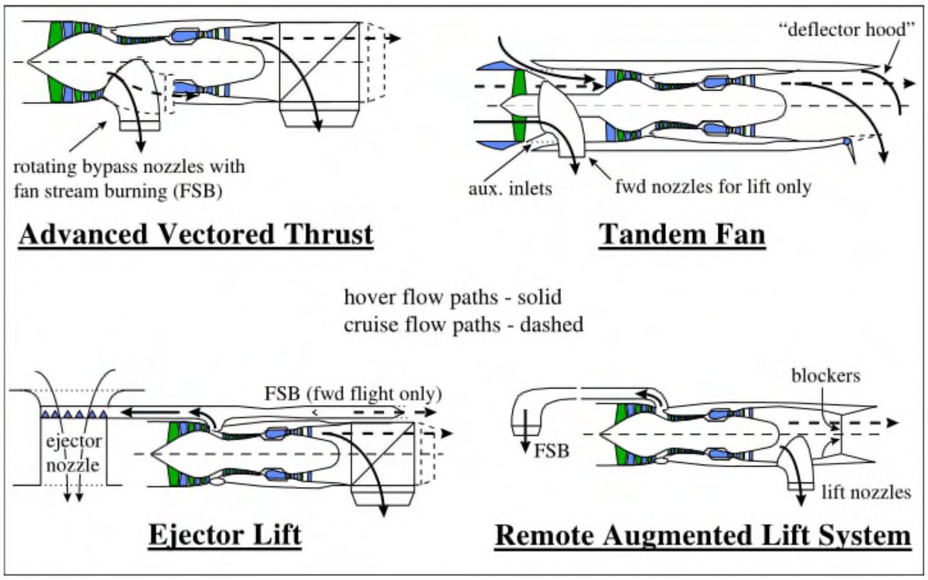


Figure 163: Initial ASTOVL Program Propulsive Lift Concepts[19]

Advanced vectored thrust (AVT): This concept "covers any system in which nozzle rotation is used to cover all phases of flight… with the **same propulsion nozzles being used throughout**." The simplest example is the Harrier. However, advanced versions were expected to use fan stream burning (FSB), both in forward flight and in hover, as the primary means of achieving supersonic performance as well as any substantial improvement in lifting capability relative to the Harrier.[20]

Tandem fan: Tandem Fan uses an extended shaft to place the first fan stage(s) well ahead of the rest of the engine. In wing-borne flight, the engine operates as any other engine except that there is a length of duct between the first and subsequent fan stages. For hover, the front fan flow is diverted into separate forward lift nozzles; at the same time the auxiliary intakes located between the two fan sections open to provide a separate air supply to the main engine. "In this way the [total effective] airflow is approximately doubled, while the jet pressure ratios are reduced" to provide high lift with a relatively benign exhaust footprint in hover.[21]

Ejector lift: In this concept, some of the engine flow is diverted to one or more "Ejector Lift" nozzles during hover. The basic principle of an ejector nozzle is the entrainment of ambient air by the primary propulsive air stream. The primary flow (that is, the flow that is drawn off from the main engine) typically exits from an array of small nozzles located inside a larger duct. When the nozzles are activated, ambient air is pulled through the duct as well, providing increased mass flow and thrust. [22]

Remote Augmented Lift System (RALS): RALS achieves lift for hover "by ducting bypass air… forward to a nozzle and auxiliary burner system placed well ahead of the centre of gravity." Core flow is also directed downward, either through a fully-vectoring rear nozzle, or through dedicated lift nozzles with the main cruise nozzle blocked off for hover. [23]

The figure illustrates an example of each concept, but considerable variation is possible. For example, most concepts may use either a fully-vectoring rear nozzle, or a flow blocker and ventral lift nozzles, to direct the main exhaust flow during hover (except AVT, which is explicitly defined as using the same nozzles at all times). Another area for variation is mixed Vs. separate flow, meaning that the bypass air may be taken off separately or combined with the core flow, either in cruise or in hover. For example, the Harrier uses separate flow at all times, with bypass air going to the forward nozzles and core air to the aft nozzles. Finally, the hover control schemes and the disposition of trim and control nozzles may vary considerably.

A.3.2 Program Management and Plans

The 1986 ASTOVL MOU established a balanced US/UK management structure for the ASTOVL program. Overall program direction was the responsibility of a four-member Executive Steering Committee (ESC). An eleven-member Joint Working Group (JWG) was responsible to the ESC for planning and execution of the approved collaborative activities. The organizations represented on the ESC and the JWG are listed in the table below. Additional working-level technical teams operated under the JWG, including a Technology Management Team, a Configuration Integration Management Team, and others as needed.

Table 30. US/UK ASTOVL Management Structure

	US	UK
Executive Steering Committee (ESC)	DoD	Ministry of Defense (MoD)
	NASA Headquarters	Royal Aircraft Establishment (RAE) Board of Management
Joint Working Group (JWG)	NASA HQ	RAE (Propulsion)
	NASA Ames	RAE (Aerodynamics)
	NASA Langley	RAE (Flight Systems)
	NASA Lewis	MoD HQ (Future Aircraft Systems)
	USAF Wright Laboratories	MoD HQ (Engines)
	NAVAIR	

A three-phased effort was planned: Concept Studies of each of the four propulsive lift concepts; a nearly-parallel Common Technology Program which would mature technologies that were generic in nature; and a Concept Specific Technology Program which would focus on technologies applicable to the one or two best concepts, once these were identified. In preparation, a 9-month Critical Survey to assess the state of knowledge of each concept in each country was conducted during 1985. Then, following the signing of the MOU in January 1986, the Concept Studies were initiated. [24]

A.3.3 Concept Studies

Contracts were awarded in 1986 for detailed, 12-month Concept Studies. The US contracts were worth approximately $0.5 million each, and were funded primarily by NASA. The UK contracts were of similar value. Each concept was studied independently by one US airframe/engine contractor team and one UK team, as shown in Table 31.

Table 31. ASTOVL Concept Studies, 1986–87

Concept	US Airframe/Engine Team	UK Team
Advanced Vectored Thrust (AVT)	McDonnell Douglas / Pratt & Whitney	British Aerospace/ Rolls-Royce (all 4 concepts)
Remote Augmented Lift System (RALS)	Grumman / General Electric	
Ejector Lift	General Dynamics / General Electric	
Tandem Fan	Lockheed / Rolls-Royce	

Due to the many possible variations of each concept, companies were asked to perform their own sub-concept screening and select one solution to develop in-depth. Contractors then conducted "complete aircraft system design, in sufficient detail to show how the various engineering problems would be solved, how the aircraft and powerplants would be controlled and how they would perform as operational military systems."

Designs were evaluated against a "Concept Evaluation Model" consisting of two sample mission profiles—one air-to-air and one air-to-surface—plus a set of point performance requirements (instantaneous and sustained maneuver, specific excess power, etc.). These did not represent any formal operational requirement, but were intended to be "ambitious but realistic" and "broadly representative of what a future multirole fighter might be called upon to do." Contractors were asked to develop data not only on how well their concept performed, but on the sensitivity of their design to possible variations of requirements and of technology assumptions. The baseline was a Technology Availability Date (TAD) of 1995.

This phase of the program was not intended to be a competition between contractors, only between concepts. Follow-on work on the selected concept(s) would be subject to an open competition and would not be restricted to those contractors who had studied the "winning" concepts in the earlier phase. Evaluation was planned for the first half of 1988, with all 8 submissions (a US and a UK design for each propulsive lift concept) to be evaluated by a single Joint Assessment and Ranking Team which reported to the Joint Working Group. [25]

A.3.4 Common Technology Program (CTP)

The second phase, referred to as the Common Technology Program, started in early 1987, in parallel with the Concept Studies. The purpose of the CTP was to mature those technologies which might be applicable to any of the ASTOVL concepts, as determined by the preliminary 1985 survey results. A secondary purpose of the CTP was to maintain the momentum of the considerable amount of STOVL-related research & development (R&D) already ongoing in both countries.

The CTP included generic research in areas such as hot gas ingestion (HGI), jet plume / structural interactions, ground environment effects, flight/propulsion control integration, and fan-stream burning. Effort focused on the development of methods and the understanding of physical phenomena, rather than on the solution of specific design problems. In late 1988, Pratt & Whitney signed a Technical Collaborative Agreement (TCA) with Rolls-Royce, to coordinate efforts on the ASTOVL program. Most CTP projects were conducted either in the US or in the UK; future activities were expected to include a greater number of integrated joint efforts. [26, 27]

A.3.5 Concept Specific Technology Program (CSTP)

The CSTP was expected to begin in late 1988, following the assessment of the Concept Studies results. It was hoped that one or two clearly preferred concepts would emerge from the Concept Studies. The CSTP would then provide significant investment in full-scale component testing, detailed analysis, and other Tech Mat necessary to reduce risk for these concepts. However, several factors changed the direction of the program before the CSTP could get underway.

First, there were no clear winners from the concept studies. All of the concepts had significant problems. Furthermore, the differences between the US contractor's and the UK contractor's implementations of each concept were in many cases as great as the differences between the different concepts.

Second, in 1987 the US Congress passed a bill known as the Nunn-Quayle Research & Development Initiative (named for its sponsors, (b)(6) [redacted] R-IN) which provided $200 million for cooperative R&D programs with other NATO countries. Of this funding, $50 million each was apportioned to the Army, the Navy, and the Air Force, with the remaining $50 million available to other defense agencies. To be eligible for this funding, a program needed an MOU with another NATO country. The partner countries were expected to match the US (b)(6) [redacted] Initiative funding.

The ASTOVL program had a signed MOU in place since January 1986. However, the program did not qualify because NASA, the lead US agency managing the program, was not a defense agency. Arrangements were therefore made for the Defense Advanced Research Projects Agency (DARPA) to join the program at this time. (b)(6) [redacted] of DARPA became the head of the ASTOVL Joint Program Office (JPO). The ASTOVL Program received $24 million of the Nunn-Quayle Initiative funding. DARPA actually received all $50 million of the "other defense agency" portion of that funding. In addition to ASTOVL, this was used to support the X-31 program (in partnership with the Federal Republic of Germany).[28]

Under DARPA's influence, the ASTOVL program became more oriented towards an eventual flight demonstration, as opposed to generic technology work and component-level demonstrations. DARPA had a recent mandate, as a result of the 1986 Packard Commission report on defense management, to play an increased role in the prototyping of military systems. This mandate was formalized in DoD Directive 5105.41, dated 30 September 1986, which revised DARPA's charter to include prototyping. DARPA also brought a higher level of military user involvement and a greater focus on actual or anticipated military requirements.[29, 30, 31]

Finally, it was becoming apparent that any new tactical aircraft effort should consider reduced observables as a means of enhancing survivability. The first true low observable (LO) military aircraft, the Lockheed F-117A, was publicly acknowledged in late 1988 (and in fact DARPA had been involved in the technology work leading up to that aircraft since 1974). LO added a whole new dimension to aircraft design.

A.4 Transitional Period, 1988-1991

Because no clearly preferred concept(s) had emerged from the Concept Studies, and because the contractors were just beginning to consider LO, it was not yet appropriate to proceed with major concept-specific demonstrations or prototype aircraft development. Instead, from 1988 through 1991 additional design and technology work was performed by the airframe and propulsion contractors, along with a variety of government studies on STOVL operational utility and related topics. Some of these efforts were sponsored by the US/UK ASTOVL program and some were sponsored by other agencies or company Independent Research and Development (IR&D or IRAD). Because of the sensitive nature of LO technology, many of these studies were classified, and/or were based upon earlier classified work. Also during this period, the US Navy, the US Marine Corps, and the UK Royal Navy developed preliminary requirements documents relating to STOVL strike/fighter aircraft. While there was some coordination of

government activities through the ASTOVL JPO and some interaction between US and UK industry, most of the individual projects still took place on one side of the Atlantic or the other. The program was known interchangeably as the ASTOVL Program or the STOVL Strike Fighter (SSF) Program. [redacted] of DARPA replaced [redacted] as Program Manager during this period.[32]

A.4.1 Revised Powered Lift Concepts

Some of the problems with the original four concepts were as follows. Advanced Vectored Thrust and Remote Augmented Lift Systems both relied on fan stream burning (FSB) to generate enough vertical thrust in hover. However, no realistic solutions to the ground environment problems associated with FSB were ever identified.

AVT had the additional problem that the cruise nozzles had to be distributed about the aircraft CG in a balanced fashion, as on the Harrier. While the Harrier design accommodated this requirement very well, it is more difficult on a stealthy, supersonic aircraft, for the following reasons:

- Supersonic aircraft normally have longer engine inlet ducts than subsonic aircraft, in order to achieve acceptable pressure recovery in supersonic flight. Longer ducts also help conceal and/or attenuate the radar and infra-red signatures associated with the engine face. However, the forward engine location required for AVT makes it difficult to integrate a long inlet duct.
- Supersonic aircraft are particularly sensitive to the way that that volume is distributed over the length of the aircraft. Putting the engine, the rotating lift/cruise nozzles, and (for balance in wing-borne flight) the wing, all at or near the aircraft CG, generally produces a large cross-sectional area in that region, resulting in high supersonic drag.
- High-energy exhaust from the centrally located, afterburning nozzles would impinge on portions of the airframe, causing intense thermal and acoustic loads.
- The nozzles would provide a heat source (hence a target for IR missiles, including both AAMs and inexpensive, shoulder-fired SAMs) right in the center of the airframe. This vulnerability was emphasized by the experiences of Desert Storm in 1991, when several Harriers were lost to IR missiles, while Tornadoes and F/A-18s survived hits in comparable situations. This was noted, "… to be a function of nozzle location rather than a single versus twin issue." [33]

All of these factors shifted the emphasis toward concepts which would not require the forward-flight nozzles to be distributed in a balanced fashion about the aircraft's CG. [34]

Even before the Concept Studies reached completion, McDonnell Douglas (the US AVT airframe contractor) modified their concept to solve some of these problems. Their new concept was called Mixed Flow Vectored Thrust (MFVT), or the "cactus." MFVT, illustrated below, took mixed exhaust flow forward to dedicated lift nozzles in order to achieve balance in hover. This is essentially the same concept that is now known as Direct Lift (DL). Because MFVT did not use any thrust augmentation in hover, it required a higher level of engine technology than the other (augmented) concepts, and was not found to be viable for a TAD of 1995.

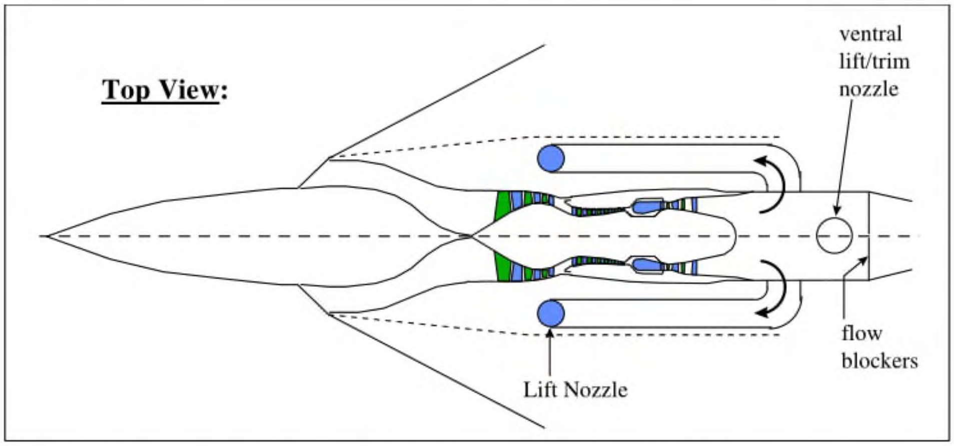


Figure 164: Mixed-Flow Vectored Thrust (MFVT), or Direct Lift concept

Ejector lift did not have the same problems as AVT and RALS, but several unsuccessful attempts had failed to demonstrate the predicted levels of thrust augmentation with ejector nozzles. These included the Lockheed XV-4A and Rockwell XFV-12A demonstrator aircraft, and more recently the General Dynamics E-7 wind tunnel tests. There were also packaging problems due to the large volume of the ducts and ejector nozzles, which created a significant performance penalty for supersonic aircraft. The E-7 project started before ASTOVL, but the programs became somewhat related since General Dynamics was the US airframe contractor for Ejector Lift in the ASTOVL Concept Studies. [35]

The remaining concept, the Tandem Fan, offered the best prospect of achieving the necessary hover thrust with a benign exhaust footprint. The chief problem with the Tandem Fan was that the switched-flow configuration provided (at least) one more fan stage in cruise than it did in hover. This resulted in too low a compression ratio in hover because the compression ratio is highest in cruise due to the ram air. In hover, where you needed the most thrust, the supercharging was lost. One solution would be to shut down the forward fan during cruise, rather than using it as an additional fan stage. With the front fan then used only for vertical lift, it made sense to orient it on a vertical axis. For this, the turbine has to be capable of driving the lift fan during hover, as well as provide efficient operation when the fan was not engaged. This dual cycle operation converts some of the jet thrust into horsepower for driving the lift fan. The Tandem Fan thus evolved into the Shaft Driven Lift Fan (SDLF). [36,37]

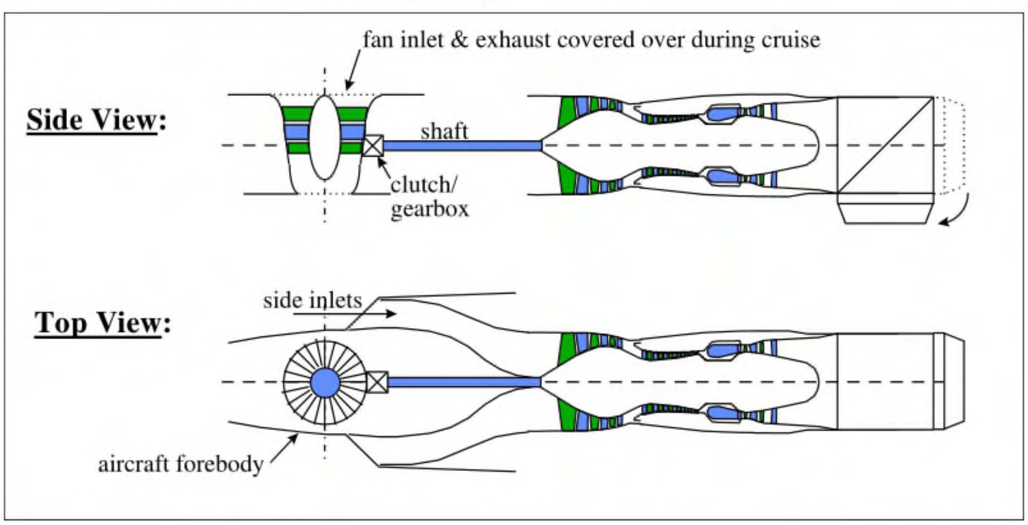


Figure 165: Representative Shaft-Driven Lift Fan (SDLF)[38]

An alternative means of powering the lift fan would be to use engine flow—either bypass or mixed—ducted forward to drive the lift fan via a turbine. Two primary variations of the Gas Driven Lift Fan (GDLF, also sometimes referred to as Gas Coupled Lift Fan (GCLF)) were considered, either with a single lift fan in the forebody or with two lift fans, one in each wing. Gas-driven wing fans had actually been studied before in various programs, and had been demonstrated in flight on the General Electric/Ryan XV-5A. [39]

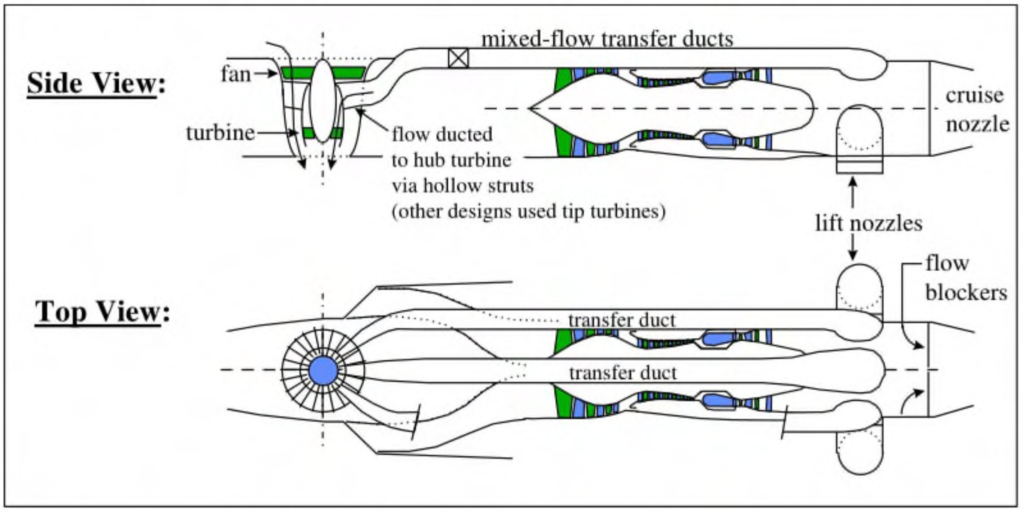


Figure 166: Single Gas-Driven Lift Fan (GDLF) in Forebody [40]

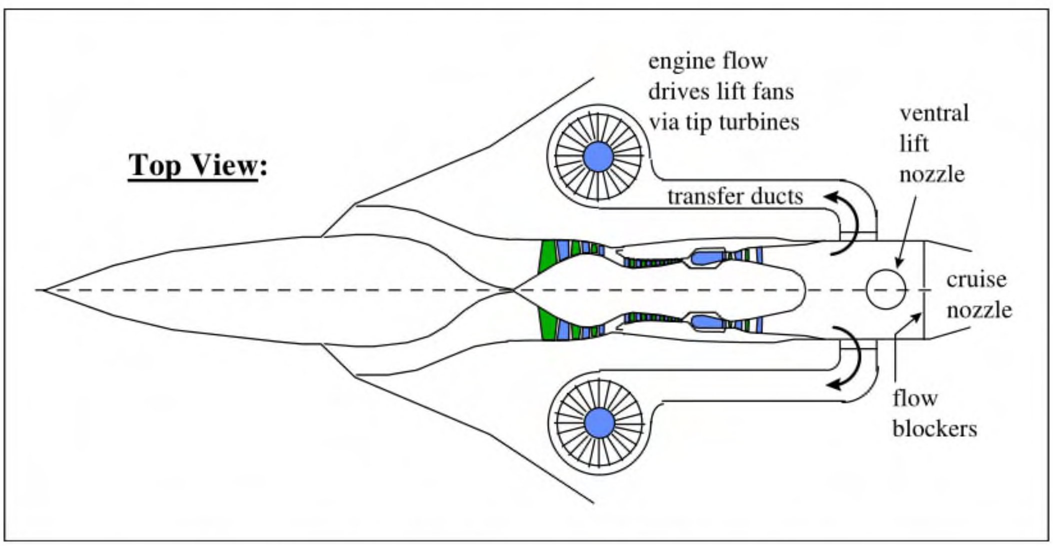


Figure 167: Twin Wing-Mounted Gas-Driven Lift Fans[41]

In addition to the lift fan concepts, interest in Direct Lift (DL) (essentially the same as McDonnell Douglas' earlier MFVT, or "cactus" concept illustrated in Figure 164) resurfaced periodically. DL derives all of its lift in hover from engine flow, with no augmentation. The lift fans were more in keeping with the original program focus on thrust augmentation. It was generally agreed that the lift fans offered a higher ultimate lifting capacity. However, DL was seen as potentially offering a simpler and lighter solution.[42]

As in the case of the earlier concepts, there are many possible sub-variations of the SDLF, the GDLF, and DL. The illustrations herein are generic, and are not representative of any particular contractors' implementations.

A.4.2 System Concept Design Studies

From 1989 through 1991, in a series of activities generally referred to as "System Concept Design Studies," the contractors redirected their efforts toward one or more of the revised powered lift concepts. Their design studies also leveraged, to varying degrees, concepts and technologies developed through other programs and/or company IR&D. In particular, the Air Force Multi-Role Fighter (MRF) Program began during this time, and some of the companies worked the same basic aircraft design in both the MRF and the ASTOVL programs. General Dynamics, McDonnell Douglas, and Lockheed Advanced Development Company (the Skunk Works) were the principal airframers involved during this period. McDonnell Douglas and British Aerospace were concurrently studying an advanced Harrier derivative (referred to as the "Harrier III"), and opinions varied as to whether or not this fell within the purview of the ASTOVL Program. In 1991 these two companies began to collaborate on all of their ASTOVL work, advanced Harrier or otherwise, and a Technology Assistance Agreement (TAA) between them was formally approved in June 1992.[43]

The preferred engines for ASTOVL included derivatives of the PW5000 and the GE 37 (these were the company designations for their respective Advanced Tactical Fighter (ATF) engines, the YF119 and YF120), along with a range of Rolls-Royce engines with various levels of advancement from the Pegasus. The derivative ATF engines generally utilized increased-flow cores, plus new LP components tailored to the needs of each particular powered lift concept. The Rolls-Royce engines were considered primarily for Direct Lift designs. Rolls-Royce also worked with Pratt & Whitney since the late 1980s under a series of TCAs and TAAs, primarily in the area of STOVL modifications and accessories for YF119-derivative engines.[44]

A.4.3 Demonstration Program Planning

While the System Concept Design Studies were underway, the ASTOVL JPO worked to develop a demonstration strategy that would provide enough confidence to eventually proceed with Engineering & Manufacturing Development of a STOVL strike fighter. DARPA strongly favored the lift fan concepts (as opposed to direct lift), and advocated a flying demonstrator program as the next step. The UK was willing to participate, even though they favored the simpler direct lift concept, but their procurement regulations prevented the MoD from funding a demonstrator program without a formal military requirement; and they did not yet have one approved. Furthermore, the original 1986 US/UK MOU was due to expire in early 1991. An extension was proposed, but the prospects for approval were uncertain.[45]

DARPA and the US Marine Corps were eager to press on, with or without formal UK participation for the time being. Since the Marine Corps did not have its own aircraft acquisition organization, it relied on NAVAIR for funding and technical support. A STOVL Utility Analysis conducted in 1990-91 by the Center for Naval Analysis (CNA) under DARPA sponsorship found that, with F119-derivative engine technology, the weight of a STOVL strike fighter to meet likely Marine Corps requirements was within 5% of the weight of a conventional carrier-based (cat/trap) aircraft designed for the same missions.[*] The Navy was interested in more ambitious range-payload requirements, where the scaling relationships still favored the conventional cat/trap approach; but this study helped secure Navy Department support for an ASTOVL program in the context of meeting an eventual Marine Corps requirement.[46, 47]

In order to "define the lowest cost options for a mission-credible flight demo program for each airframer concept," DARPA and the Navy sponsored a Low Cost Demonstration Study from June 1990 to June 1991.

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[*] The conclusions of this study cannot be extrapolated arbitrarily. Several factors cause STOVL aircraft weight to be more sensitive to increasing requirements, than CTOL or CV aircraft weight. For example, as aircraft size and weight increase, the attitude control system must become disproportionately large. Simple dimensional analysis shows that as the aircraft gross weight approaches roughly 75,000 lb, all of the available thrust must be applied at the extremities of the aircraft in order to generate sufficient attitude control in hover. For this and other reasons, large STOVL fighter-type aircraft are not practical.

Early estimates indicated that a pre-EMD flight demonstrator program would cost between $800 million and $1 billion; DARPA hoped to find ways of reducing this figure to as little as $500 million. The use of existing engines and other hardware, and various cost-saving initiatives including streamlined management and lean manufacturing, were contemplated. However, the conclusion was that a flight demonstrator would have to be full scale and fly at a weight that was representative of the proposed operational aircraft, in order to accomplish meaningful risk reduction. Shortcuts such as a subscale demonstrator using an off-the-shelf engine would cost less, but would not accomplish very much risk reduction. The other cost saving initiatives did not appear sufficient to achieve the level of cost reduction that DARPA was looking for. Gradually, $800 million became accepted as the lowest probable cost for a flight demonstrator program.[48]

The original five-year MOU expired in early 1991 and was not extended. The joint US/UK program management structure was terminated, although many activities going on in one country or the other, as well as certain collaborative arrangements, continued. The McDonnell Douglas/British Aerospace and Pratt & Whitney/Rolls-Royce teaming arrangements continued. NASA was able to keep up some of their collaborative work under a separate agreement with RAE. Government-to-government dialogue was maintained to try to establish a new joint ASTOVL program. However, there was some resistance in DoD to renewing the original MOU or developing a new one, due to concerns over the transfer of engine core, low pressure turbine, and low observable technology. (The proposed extension, mentioned earlier, was eventually signed by NASA and the UK MoD, but not by DoD.)[49, 50]

Development work at the contractors came to a virtual standstill. Studies at Lockheed Skunk Works, however, showed that a lift fan powered SSF could be modified with relative ease into a CTOL fighter, by replacing the lift fan with a fuel tank for extended range. Other STOVL-specific components could also be removed for additional weight and/or volume savings. Presentations by Lockheed to the US Air Force in Fall 1991 met with encouragement to discuss this common family of aircraft with additional DoD and Congressional staff.[51]

A.5 DARPA/US Navy ASTOVL Program, 1991-1994

By late 1991, a restructured program under DARPA/US Navy management had emerged. While the Navy had previously circulated its own Tentative Operational Requirement for a STOVL Strike Fighter, by this time NAVAIR was supporting the ASTOVL program only in the context of meeting an eventual Marine Corps requirement.[52] In the absence of formal UK participation, it was hoped that DARPA and the Department of the Navy would each contribute $400 million, although there was still some uncertainty regarding the details of how this funding would be provided. The program was structured as follows (with Phases 0 and I defined after-the-fact):

Phase 0: The early US/UK Concept Studies and Common Technology projects.

Phase I: The more recent System Concept Design Studies and related activities.

Phase II: Risk Reduction / Critical Technology Validation. Ground testing of components, powered models, etc.

Phase III: Demonstrator aircraft design, fabrication, and flight test (although flight test was sometimes referred to as a separate Phase IV).

The initial plan was to fund only one contractor for a relatively short Phase II. This would allow the program to proceed rapidly into Phase III and possibly begin flight testing as early as 1997. DARPA was assigned the designation X-32 for the STOVL demonstrator aircraft. [53, 54]

The program utilized a set of Design Guidelines that were evolved from the earlier Concept Evaluation Model, with additional mission profiles and other considerations, including affordability and supportability/deployability, added to represent likely operational requirements as well as possible. However, the philosophy was to state only a minimal number of hard "requirements" and leave all other

parameters as "goals" which could be traded off when necessary to control cost and risk. The "requirements" were:

- **"Spot Factor" less than or equal to F/A-18C** (Spot Factor is a measure of the space required on the hangar deck, with aircraft in stowed configuration).
- **Empty weight of proposed operational aircraft less than or equal to 24,000 lb.**

There was also initially a requirement for "extended supersonic range," generally interpreted to mean some level of supercruise capability. However, by the time the RFP went out (in late 1992), this was downgraded to a goal, and it was later dropped altogether.* The "spot factor" requirement insured that it would be possible to replace carrier-based Marine Corps F/A-18s with STOVL fighters one-for-one. The empty weight limit was used to keep the project technically realistic while avoiding a new engine development program. An operational STOVL aircraft must be able to hover, with an acceptable thrust margin for maneuver and control, at a weight which includes the aircraft operating empty weight plus an allowance for reserve fuel and unused stores ("bring-back" load). Based on the capabilities of any of the proposed engines, it was not considered prudent to design to an empty weight greater than 24,000 lb. Whatever else happened to the design, if its empty weight were allowed to grow, the risk of achieving acceptable STOVL capability would escalate.[55, 56]

RFP release, originally planned for late 1991 or early 1992, was delayed for several months. Part of the problem involved funding uncertainties. The recent cancellation of the Navy's A-12 Program had created considerable turmoil in the Navy's tactical aircraft procurement plans. As the situation stabilized, it became clear that the priority of a STOVL Strike Fighter (SSF) would be in a distant 3rd place, behind the Advanced Attack (A-X) and the F/A-18E/F. For this reason, "both the US Marine Corps and DARPA have made a special effort to keep the SSF Program within the DARPA prototype mandate (technology demonstrator) and out of any association with an acquisition program."[57]

Another factor hindering the RFP release was a lack of confidence within various government organizations regarding the feasibility of the concept. Additional studies were conducted in order to address some of the concerns. Two in particular had significant effects on the program—a Naval Air Systems Command (NAVAIR) Technology Assessment and a Naval Research Advisory Council (NRAC) Summer Review. [58, 59, 60]

The NAVAIR Technology Assessment addressed the question of whether a useful performance envelope could be achieved consistent with the 24,000 lb empty weight limit contained in the NAVAIR Design Guidelines. The outcome was a recommendation to delay the flight demonstration phase of the program by at least a year, in order to expand the Phase II Risk Reduction ground test activities—not only to do additional testing, but also to carry two concepts through this phase instead of one. (b)(6) [redacted] head of the Systems Technology group at NAVAIR (responsible for Science & Technology programs) was the chief proponent of this idea. Under the revised plan, two contractors would be selected for Phase II—one GDLF and one SDLF. Each contractor would fabricate and test a Large Scale Powered Model (LSPM) in order to demonstrate the performance of the powered lift system, and to assess ground effects, hot gas ingestion, jet effects interactions, and other issues with confidence that could only be provided by near-full-scale testing. Final downselect to a single contractor/concept would not be made until this testing was accomplished. [61, 62]

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* This requirement may have been based on an expectation that supercruise capability would be a "fallout" due to the high thrust-to-weight ratio required for STOVL, and/or the use of an ATF-derived engine. However, supercruise also depends on a high fineness ratio (long and thin) and a well-managed distribution of volume over the length of the aircraft. STOVL aircraft, on the other hand, tend to be shorter (to minimize empty weight, particularly with the 24,000lb limit), wider (to accommodate the powered lift system), and their volume distribution is highly constrained by wing-borne and jet-borne balance requirements, making it difficult to optimize for supercruise. At the same time, the Navy—the prime driver behind a supercruise requirement—basically lost interest in ASTOVL apart from the Marine Corps, who were more willing to compromise in this area.

The NRAC review was requested during early 1992 by Mr. Gerry Cann, the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN/RD&A, the Navy's Service Acquisition Executive). The review was intended to address the operational need for the SSF, technical risks, advantages and disadvantages of SSF compared to CTOL. The review was conducted in late June, and the report was presented to Mr. Cann in late July. Not only was the report very positive overall; the study concluded that many of the advanced concepts and technologies that would enable a STOVL fighter to achieve the stated mission and affordability goals, would also be applicable to a next-generation CTOL multirole fighter. The report recommended that DARPA and USN collaborate with the USAF, and expand the program to include a modular STOVL/CTOL family, in which the powered lift equipment could be replaced with additional fuel capacity in the USAF CTOL variant. Such an aircraft could conceivably meet the USAF's MRF need, and would provide enhanced affordability for both services through a large production run of a single basic airframe. With this new emphasis, the program adopted the title Common Affordable Lightweight Fighter (CALF). [63, 64]

By this time, the prime contractors had all converged on their preferred concepts. General Dynamics, who had previously studied the Ejector Nozzle concept with a bank of ejector nozzles in each wing, adopted the GDLF with two lift fans located in the wings. Lockheed chose the SDLF, which was a logical evolution from the Tandem Fan they had investigated during the original ASTOVL Concept Studies. McDonnell Douglas (teamed with British Aerospace) chose the SDLF and a GDLF design in order to improve their competitive position, once it became apparent that the JPO intended to pick one SDLF and one GDLF for Phase II. Each airframe company conducted its own engine selection, roughly in parallel with the Phase II competitive selection process. During early 1992, Grumman and Northrop also began to show an interest in the program. Grumman had a GDLF concept that was based on earlier US Army Advanced Close Air Support (ACAS) and USAF Special Operations Forces projects, while Northrop did not yet have a selected concept. [65]

A solicitation synopsis was published in the *Commerce Business Daily (CBD)* on 24 March 1992, before the NRAC study was completed. The full RFP was released in August 1992, with proposals due on 5 December. A total of six proposals were received from five companies as follows:

- Boeing—Direct Lift
- General Dynamics—Twin, tip-driven GDLFs in wings
- Grumman—Twin, tip-driven GDLFs in wings
- McDonnell Douglas (2 proposals)—SDLF, and GDLF design with single fan in forebody
- Lockheed (Skunk Works)—SDLF

The Boeing proposal was the most unexpected; it had been quickly adapted from a Boeing MRF study configuration, at the urging of Boeing management who perceived that the USAF MRF Program was likely to be cancelled. Northrop did not submit a proposal at that time. [66, 67]

An Advanced Development Project Office (ADPO-17) was formed at NAVAIR during late 1992 to provide technical support to the program during the source selection and subsequent phases. The initial NAVAIR staff consisted of [redacted] (aerodynamics/ performance), [redacted] (weights), [redacted] (propulsion), and Col [redacted] (Chief Engineer /Navy Deputy Program Manager).[*] At around the same time, [redacted] left the program to become Deputy Director of the Advanced Systems Technology Office (ASTO) at DARPA, and Col [redacted] served as acting program manager. In September 1993, [redacted] who had been supporting the program for several years as an employee of DGI Analysis & Engineering, was hired by DARPA as the new full-time ASTOVL Program Manager. [68, 69]

On 15 March 1993, the contracts for Phase II, Critical Technology Validation (also referred to as Risk Reduction) were awarded. Lockheed, teamed with Pratt & Whitney for the main engine and Allison/Rolls

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[*] All of whom were still with the JSF Program through the beginning of the JSF Concept Demonstration Phase.

Royce for the lift fan and other powered-lift items, was awarded $32.9 million for the Shaft Driven Lift Fan concept. The team of McDonnell Douglas and British Aerospace, along with General Electric and Rolls Royce, was awarded $27.7 million for the Gas Driven Lift Fan. Both contracts also called for some level of company contribution. [70, 71] Lockheed's "Configuration 100" design is shown in Figure 168, while McDonnell's design was illustrated in Figure 9.

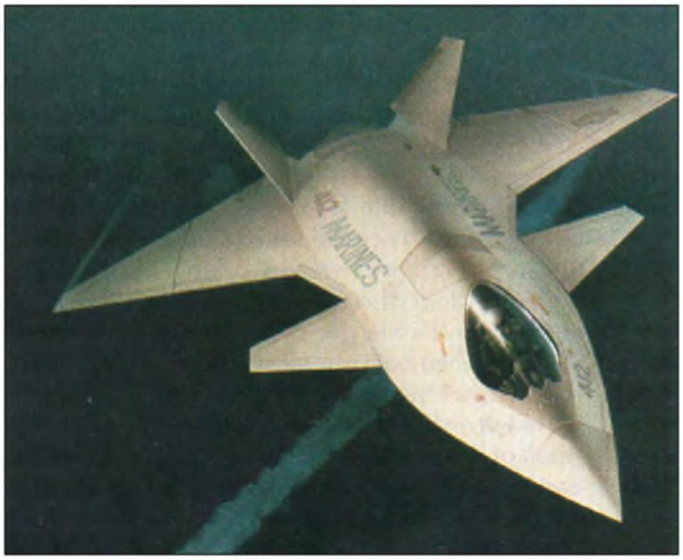

Figure 168. Artist's rendering of the early Lockheed ASTOVL concept

The goals of this phase of the ASTOVL Program were to demonstrate the feasibility—through design analysis, subscale/component testing including small scale powered models (SSPMs), and large scale powered model (LSPM) testing—of a common, affordable, lightweight fighter capable of either CTOL operations for the US Air Force or STOVL operations for the US Marine Corps and Royal Navy (despite the lack of an MOU, the UK had contributed some funding for the program); and to enable the knowledgeable selection of a single design concept for the subsequent flight demonstration phase. Specific prime contractor tasks were:

- Design analysis and capability trade studies for SSF and USAF CTOL aircraft with maximum commonality.
- Affordability analyses and innovative process development/ demonstration.
- Large Scale Powered Model tests and demonstrations.
- Propulsion system component analyses & demonstrations.
- Operational aircraft design refinement, and demonstrator aircraft (Phase III) design and planning. [72]

Although Boeing was not awarded a contract, they signed a technology sharing agreement with DARPA on 22 May 1993, allowing Boeing to continue their participation in the program as a company-funded IR&D activity. However, as a result of lobbying by Boeing, Congress subsequently added $6 million to DARPA's FY94 ASTOVL budget for the specific purpose of continuing to investigate Direct Lift as an alternative to the lift fan concepts. Although the program had deliberately focused on lift augmentation concepts, (b)(6) [redacted] the DARPA Program Manager, stated that he was prepared to let the Direct Lift concept compete on its own merits. DARPA released a solicitation for a Direct Lift CALF in late 1993, specifying that the contract would be awarded on an equal cost sharing basis. Boeing was the only respondent, and in March 1994, Boeing was awarded a cost-sharing contract with a total value of $12 million for the first year ($6 million each from DARPA and Boeing). An additional $10 million was planned to be provided by each party for the second year, bringing the total to $32 million. The Large Scale Powered Model testing and the propulsion system component demonstrations were initially included as options in

the Boeing contract, but once DARPA's share of the 2nd year funding became firm, these tasks became requirements. [73, 74, 75] Boeing's design is shown in Figure 169.

Figure 169. Artist's rendering of the Boeing concept

Northrop, which had been evaluating STOVL as a "low-level option" in its USAF MRF studies, eventually adopted a "Lift plus Lift/Cruise" (L+L/C) propulsion concept: a dedicated lift engine in the forebody and thrust vectoring or blockers/lift nozzles on the main engine. Northrop considered proposing this in response to DARPA's late-1993 Direct Lift solicitation, but was advised that their L+L/C concept did not qualify. However, the company was able to join the program during 1994 on a no-cost contract. By mid-1994 DARPA was treating all four prime contractors essentially equally with respect to formal reviews, program information, etc., regardless of the type of contract. [76]

Negotiations with the UK for a new MOU were begun in early 1993. The new MOU was signed in August 1994, following which a UK Deputy, Commander Phil Hunt, RN, was assigned to the ASTOVL Program Office. Provisions of the MOU were as follows:

- Covered Phase II (Risk Reduction/Critical Technology Validation) of the ASTOVL Program.
- Funding share was nominally 65% US and 35% UK (this was noted to be approximately the minimum foreign share that would be approved as a collaborative program by DoD). [77]
  - $12 million direct financial contribution to be provided by UK MoD
  - Remainder as "work in kind," i.e., R&D performed in the UK with UK funding, use of UK test facilities, etc.

DARPA distributed the $12 million MoD funding equally between the Lockheed and McDonnell Douglas contracts. The MOU did not address the technology transfer issues relating to low observables, engine core, and low pressure turbine technology. However, it did contain a statement "committing both governments to best efforts to resolve this impediment to full collaboration." [78, 79]

Meanwhile, the results of the DoD Bottom Up Review (BUR) were announced in September 1993. The BUR resulted in termination of both the USAF MRF and the USN Advanced Attack Fighter (A/F-X) programs, and launching of the JAST Program. JAST was chartered to mature technologies, develop requirements, and demonstrate concepts for affordable next-generation joint strike warfare. As JAST plans took shape, it became apparent that JAST would be funding one or more concept demonstrator aircraft starting in 1996–about the time the ASTOVL program planned to enter its Phase III (full-scale flight demonstrators). The ASTOVL project, as an advanced concept for a future joint-service strike/fighter, appeared consistent with the JAST charter. It was therefore agreed by the management of both programs, that JAST would become the US service "sponsor" for the flight demonstration phase of ASTOVL, if Phase II were successful *and* if the concept appeared to be able to satisfy the requirements of at least two of the three US services participating in JAST.

However, FY95 budget legislation passed in October 1994 by the US Congress directed that ASTOVL be merged into JAST immediately. A timeline of all the ASTOVL-related activities up to the time when it merged with JAST is given in Figure 170.

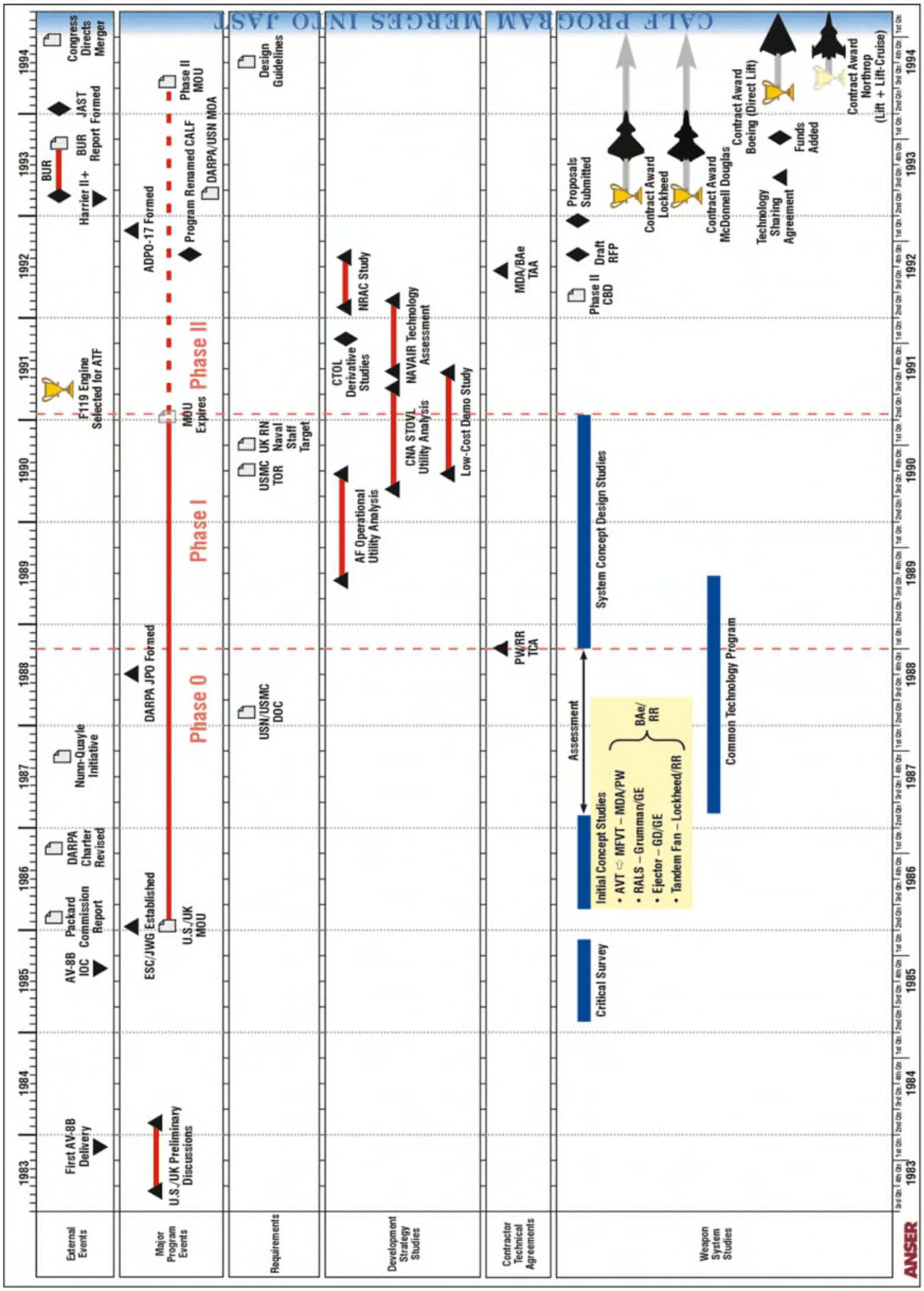

Figure 170. Timeline of Major ASTOVL Activities and Events, 1983-1994 [80, 81]

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[2] [redacted] Deputy Director, JSF Science & Technology Directorate, Interviewed by [redacted] 8 October 1997 and 23 January 1998.
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[4] [redacted] Col USMC, JSF Systems Engineering Director (formerly ASTOVL Deputy Program Manager (Navy)), Interviewed by [redacted] 7 April 1998.
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[19] Armstrong and Levine, 1987.
[20] *Ibid.*
[21] *Ibid.*
[22] *Ibid.*
[23] *Ibid.*
[24] *Ibid.*
[25] *Ibid.*
[26] *Ibid.*
[27] [redacted] 1994.
[28] [redacted] 1997-8.
[29] [redacted] Lt Col USAF, *Point Paper on DARPA Prototyping*, Office of the Assistant Secretary of the Air Force (Acquisition), SAF/AQT, 20 December 1991.
[30] *An Interim Report to the President* by the President's Blue Ribbon Commission on Defense Management (the "Packard Commission"), 28 February 1986.
[31] [redacted] 1997-8.
[32] *Ibid.*
[33] STOVL 2000 Executive Steering Committee (Pratt & Whitney / Rolls-Royce), *Meeting 013 Minutes*, Epcot Center, Orlando, FL, 27 March 1991 [Note: This was an engine industry (P&W/RR) committee, as distinct from the government Executive Steering Committee mentioned in the text, which had overall program direction responsibility for the collaborative U.S./U.K. ASTOVL Program].
[34] [redacted] 1997-98.
[35] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes*, and *Meeting 018 Minutes*, Buckingham Gate, United Kingdom, 23 June 1992.
[36] [redacted] 1997-98.
[37] [redacted] "Dual Cycle Operation of the Shaft Driven Lift Fan Propulsion System," International Powered Lift Conference Proceedings, March 1997.
[38] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes* and *Meeting 018 Minutes*.
[39] STOVL 2000 Executive Steering Committee, *Meeting 011 Minutes, Meeting 013 Minutes,* and *Meeting 018 Minutes*.
[40] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes*.
[41] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes* and *Meeting 018 Minutes*.
[42] *Ibid.*
[43] STOVL 2000 Executive Steering Committee, *Meeting 011 Minutes*, Bristol, England, 10 September 1990, *Meeting 013 Minutes*, and *Meeting 018 Minutes*.
[44] *Ibid.*
[45] STOVL 2000 Executive Steering Committee, *Meeting 011 Minutes*.

[46] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes*.
[47] [redacted] 1997-98.
[48] STOVL 2000 Executive Steering Committee, *Meeting 011 Minutes* and *Meeting 013 Minutes*.
[49] STOVL 2000 Executive Steering Committee, *Meeting 011 Minutes, Meeting 013 Minutes,* and *Meeting 018 Minutes*.
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[55] STOVL 2000 Executive Steering Committee, *Meeting 013 Minutes*.
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[58] *Ibid.*
[59] Wilson, 1997-8.
[60] *STOVL/CTOL Common Affordable Lightweight Fighter*, 1993.
[61] *Ibid.*
[62] [redacted] 1997-98.
[63] STOVL 2000 Executive Steering Committee, *Meeting 018 Minutes*.
[64] *STOVL/CTOL Common Affordable Lightweight Fighter*, 1993.
[65] STOVL 2000 Executive Steering Committee, *Meeting 018 Minutes*.
[66] *Ibid.*
[67] [redacted] 1997-98.
[68] *Ibid.*
[69] [redacted] 1997.
[70] *Jane's All the World's Aircraft*, 1994-95 Edition.
[71] *STOVL/CTOL Common Affordable Lightweight Fighter*, 1993.
[72] *Ibid.*
[73] *Ibid.*
[74] [redacted] 1997-8.
[75] STOVL 2000 Executive Steering Committee, *Meeting 024 Minutes*, West Palm Beach, Florida, 10 December 1993, and *Meeting 026 Minutes*, Bristol, England, 24 June 1994.
[76] *Ibid.*
[77] *Ibid.*
[78] *Ibid.*
[79] [redacted] "Northrop Sees ASTOVL as Inroad to JAST," *Aviation Week and Space Technology*, 1 August 1994, pp. 27-9.
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[81] *STOVL/CTOL Common Affordable Lightweight Fighter*, 1993.

Appendix B: Historical Documents

JAST Memorandum, Dr. John Deutch, August 1993

11 August 1993

MEMORANDUM FOR SECRETARY OF THE NAVY
SECRETARY OF THE AIR FORCE

SUBJECT: Joint Advanced Strike Technology

One of the key areas likely to emerge from the bottom-up review that deserves an early start is a comprehensive advanced strike technology program to support the development of next generation fighter/strike aircraft. It is the Secretary's intent that this program focus on key technologies to meet future joint operational requirements while reducing cost and risk. Additionally, we must aggressively take full advantage of DSB findings and recommendations.

The JAST Program should include:

1. Common component development, e.g., engines, avionics, ground test and training equipment that will be required to be employed in future aircraft.
2. Modern precision guided munitions and advanced mission planning techniques.
3. Technology demonstration of advanced aircraft concepts.
4. A balance of manned and unmanned system concepts.

I would like you to recommend, jointly, a plan to support all aspects of the development. As a minimum, that plan should identify the lead service for the initial phase of the program (I will rotate the lead every three years), and address the specific technologies to best support operational requirements. The plan should include producibility and lean manufacturing concepts, identify the joint organization to support this plan, and provide your views on transitioning these technologies to operational prototypes/demonstrations. Your recommendations should include projected funding requirements over the next five years with estimates beyond. In order to support consideration in the ongoing budget process, the plan must be finalized by November 1, 1993, at the latest.

Please coordinate your efforts through Frank Kendall [Director, Tactical Systems, Office of the Under Secretary of Defense (Acquisition)] and Larry Lynn [Deputy Under Secretary of Defense for Advanced Technologies], and provide me with a status report within 30 days.

[signed] John M. Deutch

JAST Charter

CHARTER
for the

JOINT ADVANCED STRIKE TECHNOLOGY (JAST)

PROGRAM

Approved by:

DEPUTY SECRETARY OF DEFENSE

[signed]

John M. Deutch

Date 12 August 1994

SECRETARY OF THE AIR FORCE	**SECRETARY OF THE NAVY**
[signed]	**[signed]**
Sheila E. Widnall	**John H. Dalton**
Date MAR 30 1994	**Date** 26 May 1994

CHARTER FOR THE
JOINT ADVANCED STRIKE TECHNOLOGY (JAST) PROGRAM

BACKGROUND

The Under Secretary of Defense for Acquisition and Technology (USD(A&T)) Memorandum of 11 August 1993 formally requested a joint Air Force/Navy plan to implement the JAST Program as a comprehensive advanced technology effort to prepare the way for the next generation of strike weapon systems. On 1 September 1993, the Secretary of Defense briefed OSD's Bottom-Up Review and formally announced his intent to cancel the Navy AFX and Air Force MF [*sic*] programs and create the JAST Program. On 12 October 1993, USD(A&T) approved the initial joint service plan for the JAST Program. On 14 October 1993, USD(A&T) sent letters to the Chairmen and the Ranking Minority Members of the Defense Committees announcing his approval of the joint service plan and soliciting their support. On 9 December 1993, the Deputy Secretary of Defense endorsed the JAST Program strategies. On 27 January 1994, USD(A&T) formally established the JAST Program.

To ensure future tactical air capability at affordable costs, the DOD Bottom-Up Review determined that the Department should, in the near term, only make those choices needed to meet current deficiencies and to enable future options. Therefore, the JAST Program will bring the Navy, Air Force, and Marine Corps together to work jointly at reducing costs of future strike warfare concepts by jointly maturing/transitioning advanced technologies, components, and processes. The JAST Program will develop, validate, and demonstrate operational concepts responsive to user-defined requirements. The JAST Program will "set the stage" within government and industry to reduce cost and risk such that effective and affordable weapon systems can rapidly enter development. The vision of the JAST Program is *a joint services team creating the building blocks for affordable, successful development of next generation strike weapons systems*.

PURPOSE/MISSION

The JAST Program is chartered to facilitate evolution of fully developed and validated operational requirements, proven operational concepts and mature, demonstrated technologies to support successful development and production of next generation strike weapon systems for USN, USMC, USAF and our allies.

The JAST Program will provide focus and direction to future strike technology by applying a strategy-to-task-to-technology analytical process involving an integrated team of users and developers. User defined future operational needs will determine which technologies and demonstrations will be pursued and funded. The JAST Program will serve as the critical link between the requirements community, the technology community, and an eventual acquisition program office(s). The JAST Program Director will facilitate a marriage between the Services' requirements communities in order to assist them in developing a set of joint requirements to guide the effort, and evolve these requirements over time consistent with technology's ability to support them.

The breadth of potential JAST Program investment spans: common component development (e.g., engines, avionics, and ground test and training equipment; modern precision guided munitions, advanced mission planning techniques, etc); advanced concept technology demonstrations; and manned and unmanned system concepts. The JAST Program will interact with existing organizations in these areas to focus investments, conduct concept integration and demonstrations as needed to mature both the technology and the operational concepts.

The JAST Program will focus on reducing both cost and risk of technologies, processes, and concepts to meet future joint operational needs. The goal is to demonstrate technologies and manufacturing processes that will reduce life cycle costs of future systems, and promote application of commercial practices and technologies where appropriate. The JAST Program will jointly transition high leverage technologies,

components, and processes to facilitate the Services proceeding with formal, system level development of affordable next generation strike weapon systems.

The emphasis is on maturing and demonstrating those technologies, components, concepts and manufacturing processes which optimize commonality between the Services' next-generation strike weapon systems, through prudent use of design modularity and common components. While the silhouettes may conceivably need to look difference for operational needs, the various concepts would have a high degree of cost commonality. In concert with OSD, the Services, and other agency technology developers (NASA, ARPA, etc.) the JAST Program will serve as the primary DOD authority for:

- Focusing investments with the paramount objective of reducing future strike systems development, procurement, and support costs;
- Triggering unprecedented levels of joint analysis and simulation, spanning the spectrum from battlefield campaigns to drawing board concepts;
- Identifying and leveraging commercial sector technologies and processes for application to strike technologies and manufacturing processes;
- Prioritizing DOD's investments in technology projects related to strike warfare;
- Constructing, in concert with the user communities, strike technology development roadmaps;
- Initiating focused technology/concept demonstrations with the objective of assessing operational utility and payoff, validating their technical maturity, and developing an understanding of the residual risk of transitioning to weapon system development;
- Performing tradeoff analyses of critical user defined performance parameters for the next generation strike systems;
- Identifying how to apply "lean enterprise" concepts to the development and production of next generation strike weapon systems; and
- Identifying dual use applications for those technologies and processes developed under the JAST Program.

The JAST Program Office will not transition to a future program office, but if successful may continue as a technology program to focus on high priority technology development areas of interest, as directed by USD(A&T). The initial JAST Program window for investments is on technologies and processes which can be brought to a sufficient level of maturity to permit transition to a formal program(s) to support weapon system fielding in approximately 2010.

MANAGEMENT AUTHORITY AND RESPONSIBILITY

A. Scope

The JAST Program is a joint service organization, staffed by Air Force, Navy, and Marine Corps personnel. The JAST Program Office shall serve as the focal point for developing and implementing a strategy that focuses the future strike warfare operational needs of the requirements community and integrates those needs with the technology programs of DOD, ARPA, NASA, etc.

The JAST Program Director has authority to interact with OSD, Service, and other agency technology organizations to focus and integrate technology activities in support of responsibilities listed in this charter. Across the spectrum of JAST Program efforts, the Director will seek out and apply streamlined and innovative practices. Where appropriate, he will coordinate with the Under Secretary of Defense for Acquisition Reform (USD(AR)) to obtain waivers or exceptions to statutory requirements.

In supporting the JAST Program, Service Secretaries will provide resources and ensure compliance with this charter. Specifically, the JAST Program resides under the Assistant Secretary of the Navy for Research,

Development, and Acquisition (ASN(RDA)) for Navy and Marine Corps support and under the Assistant Secretary of the Air Force for Acquisition (SAF/AQ) for Air Force support. The Services will support a two-star level (or equivalent) Advisory Group to act as a sounding board and support forum for the JAST Program Director and the Service Acquisition Executives (SAEs). Additionally, an Executive Committee chaired by USD(A&T) will be supported by the Services to act as an advisory body to the USD(A&T) on the JAST Program. The Office of Tactical Warfare Programs is designated Office of Primary Responsibility within OUSD(A&T) for management and administration of the JAST Program. Refer to the Organization and Staffing section for details.

B. Business Operations

The JAST Program will budget and execute funding for investments approved by the USD(A&T). The FY1994 Defense Appropriations Act provided Navy funding for the initiation of JAST. The Navy and Air Force have budgeted equal funding within Service TOAs across the FYDP beginning in FY1995. Funding is RDT&E Category 6.3B in nature, however the JAST Program will have latitude to fund efforts across the development spectrum and for Program Office functions (e.g., training, travel, office facilities, administrative/technical support, etc.). The JAST Program is not an "acquisition Program" as defined in DODI 5000. For documentation and reporting purposes, the JAST Program will summarize activities in a JAST Program Annual Report & Master Plan (a single document). The JAST Program will coordinate with established comptroller and accounting organizations in the Washington, DC metropolitan area for appropriation accounting and funds administration functions.

The JAST Program is a joint service program with no executive service. Since the Navy and Air Force program elements that fund the program are inextricable linked, the programming and comptroller organizations of the respective Services should be especially mindful of the ramifications of potential funding changes by either Service. Care should be taken to ensure that consistency is maintained between the Services' budget documentation as it proceeds through the respective Service chains.

C. Contracting Activities

The JAST Program is authorized to establish an in-house contracting ability (to include source selection authority), although it is envisioned that most activities will be passed to the Services for execution. When asking the Services to execute activities, the JAST Program will provide written direction and appropriate funding. Close coordination with USD(AR) will be maintained to provide a resource organization that can implement pilot efforts.

D. Security

The JAST Program Director will establish and maintain a Program Protection function to ensure security costs and administrative requirements are reduced to the minimum required to protect the critical enabling technologies handled by the JAST Program Office. The JAST Program Director will implement appropriate security measures for access to special programs.

OSD and the Services will provide Technical Security and Foreign Intelligence Threat support to the JAST Program Director.

RELATIONSHIP TO OTHER PROGRAMS AND ORGANIZATIONS

In the accomplishment of assigned tasks, the JAST Program will interact with all applicable DOD, other agency, and industry technology organizations. The JAST Program Director will be a key participant in the Services' Project Reliance effort to assist in deconflicting efforts and to provide an operational focus to their investment plans. Similar interaction will be accomplished with DDR&E, DUSD(A&T) and supporting staffs. Of primary importance is close communication and cooperation with the user/operator communities to ensure that both ongoing and recommended technology development have operational

utility. The JAST Program Director and his staff are to be afforded rapid insight into all applicable planned and ongoing efforts including special access initiatives.

The Services will access key JAST Program personnel to applicable special access programs. The JAST Program Security Director will assist the Services in jointly developing procedures for protection of special access program information maintained by the JAST Program. The Services will provide a focal point to resolve special access concerns.

REPORTING AND INFORMATION REQUIREMENTS

The JAST Program Director reports to the opposite Service Acquisition Executive. An Advisory Group, as depicted in Attachment 1, is established to provide advice on Service related matters ad to provide support to the Program Director. An Executive Committee (EXCOM), as depicted in Attachment 1, functions in an advisory capacity to USD(A&T) and the Service Acquisition Executives.

The JAST Program Director will not be required to pre-brief or coordinate through the multitude of supporting staffs of the members of the Advisory Group and EXCOM. Similarly, briefings will be presented to the Advisory Group and EXCOM as a group. The JAST Program Director will prepare both an agenda and issue papers, and distribute them to the designated members of the Advisory Group and the EXCOM prior to scheduled reviews. Informal meetings with the SAEs and USD(A&T) are encouraged.

The JAST Program is a non-ACAT program. Therefore, the principal document of the JAST Program will be an Annual Report & Master Plan. The Annual Report & Master Plan consists of a Summary of current and previous efforts, a Technology Roadmap to cover the FYDP, and a proposed Investment/Execution Plan, with detailed justification for the next budget year. Decisions made by the USD(A&T) will be incorporated into JAST activities and reflected in the Annual Report & Master Plan. Comments made by the Advisory Group will not be taken as directive in nature but will be addressed in the briefing to the SAE for consideration and potential inclusion prior to review by the EXCOM.

The JAST Program will endeavor to be a paperless operation. All organizations interacting with the JAST Program will assist this goal by facilitating acceptance of electronic media reports, data, or documents.

ORGANIZATION AND STAFFING

The JAST Program will be a jointly manned activity. It will be staffed by Air Force, Navy, and Marine Corps personnel, with allowances for an Army liaison if later deemed appropriate. The program office will be located in the Washington, DC area. The JAST Program Director will report to USD (A&T) through the SEA [*sic*]. For performance or fitness report purposes, the JAST Program Director will be rated by the opposite SAE and forwarded to his service Vice Chief for review. Details of the organization reporting chain and the composition of the EXCOM and Advisory Group are contained in attachment 1.

The JAST Program Director will be an 0-8 from one Department and the Deputy will be an 0-7 from the opposite Department. These positions will periodically alternate between the Department of the Air Force and the Department of the Navy. The Services may, if so desired, balance the 0-8 and 0-7 positions with operator and acquisition personnel, with final approval of USA (A&T). The organization and staffing requirements are contained in Attachment 2. A permanent Chair is authorized as deemed necessary.

The Navy, Air force, and Marine Corps will detail operator/user personnel to the JAST Program Office on a PCS basis to represent their parent Service. Ten accredited Joint Duty billets will be established for the JAST Program and manned as indicated in Attachment 2, pages 9-11. One of the ten billets will alternate between Director and Deputy Director positions. The Services will also establish a Requirement Support Group which will be made up of operational experts from the Services who will execute the Strategy-To-Task-To-Technology process and provide continuing operational expertise to the operators/users resident in the JAST Office.

For Air Force personnel assigned to the JAST Program, The JAST Program Director will aggregate his "Definitely Promote" and "Promote" ratings under SAF/AQ.

<u>JOINT OPERATING PROCEDURES (JOPS)</u>

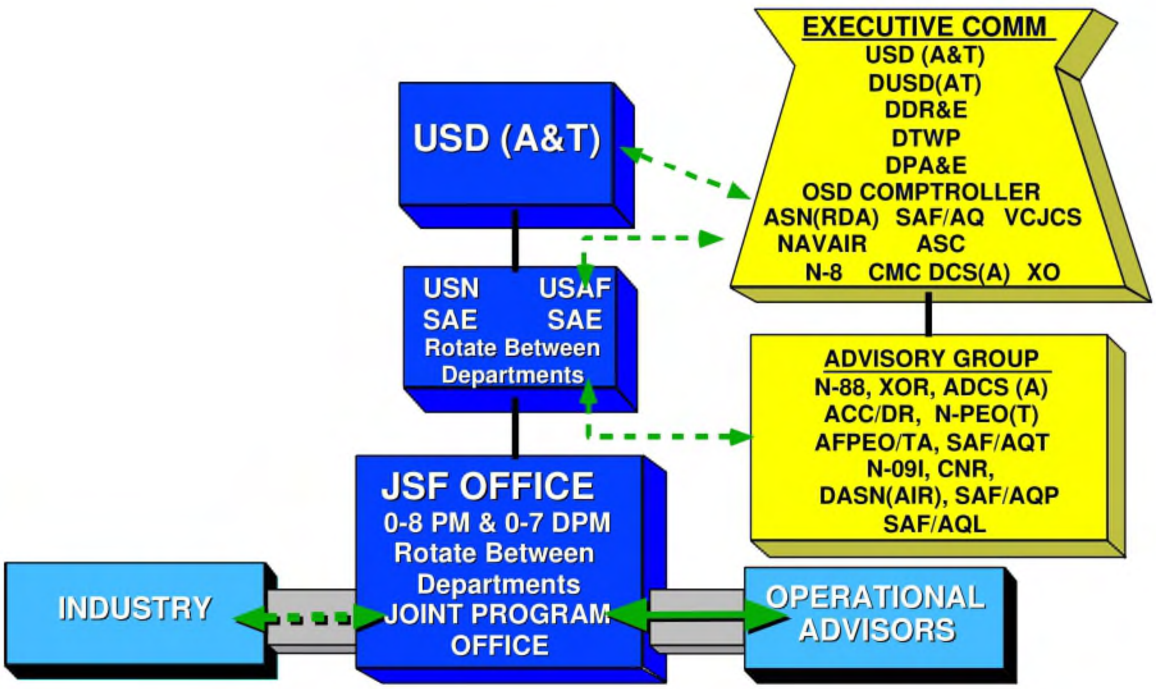
If deemed necessary by the JAST Program Director, The JAST Program Office will identify and describe detailed procedures and agreements to carry out significant aspects of the joint program. The JAST Program Director and designated officials in each Service will negotiate and implement required JOPs.

<u>JAST PROGRAM CHARTER REVIEW AND UPDATES</u>

The JAST Program will review the charter and issue revisions as required. Modifications require USD(A&T) approval.

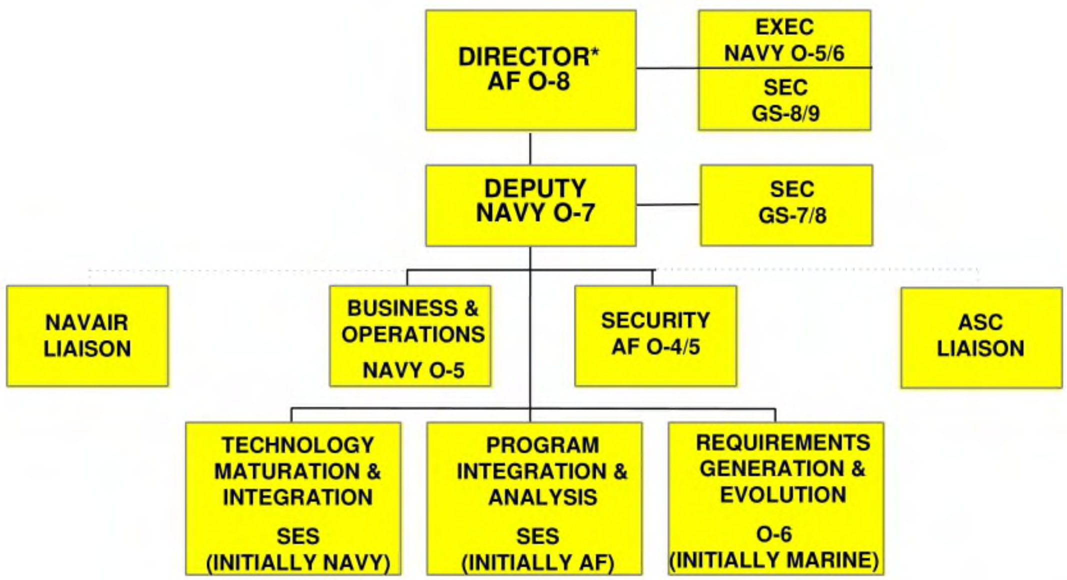
Attachment 1

JSF ORGANIZATIONAL RELATIONSHIPS



Attachment 2

INITIAL JAST ORGANIZATION



39 - 50 TOTAL
(EXCLUDING NAVAIR/ASC MATRIX SUPPORT)

<u>**NOTE**</u>

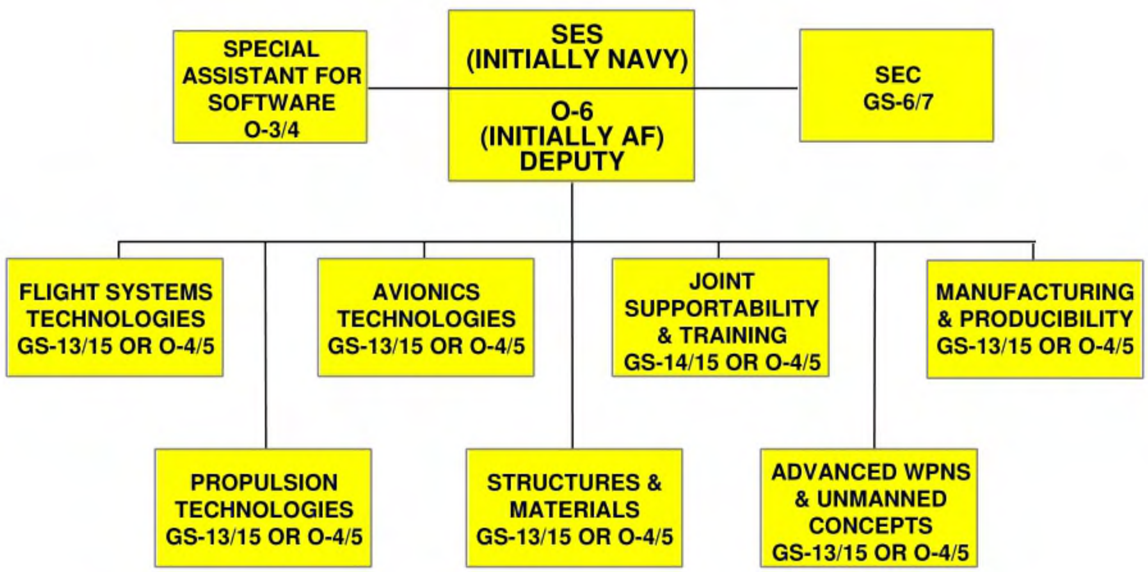
ORGANIZATION REFLECTS "STRUCTURED" RELATIONSHIPS FOR PERSONNEL PLANNING PURPOSES ONLY. JAST WILL ACTUALLY OPERATE AS A FLEXIBLE, IPT OOORIENTED GROUP(s), WHERE ROLES AND RELATIONSHIPS MAY CHANGE AS A FUNCTION OF PRODUCT EMPHASIS AND PROJECT DIRECTOR OBJECTIVES

KEY POSITIONS (SES AND SENIOR OFFICER) SHOULD BE BALANCED BETWEEN THE SERVICES

TEN JOINT DUTY BILLETS REQUIRED. * DENOTES JOINT BILLET

Attachment 2

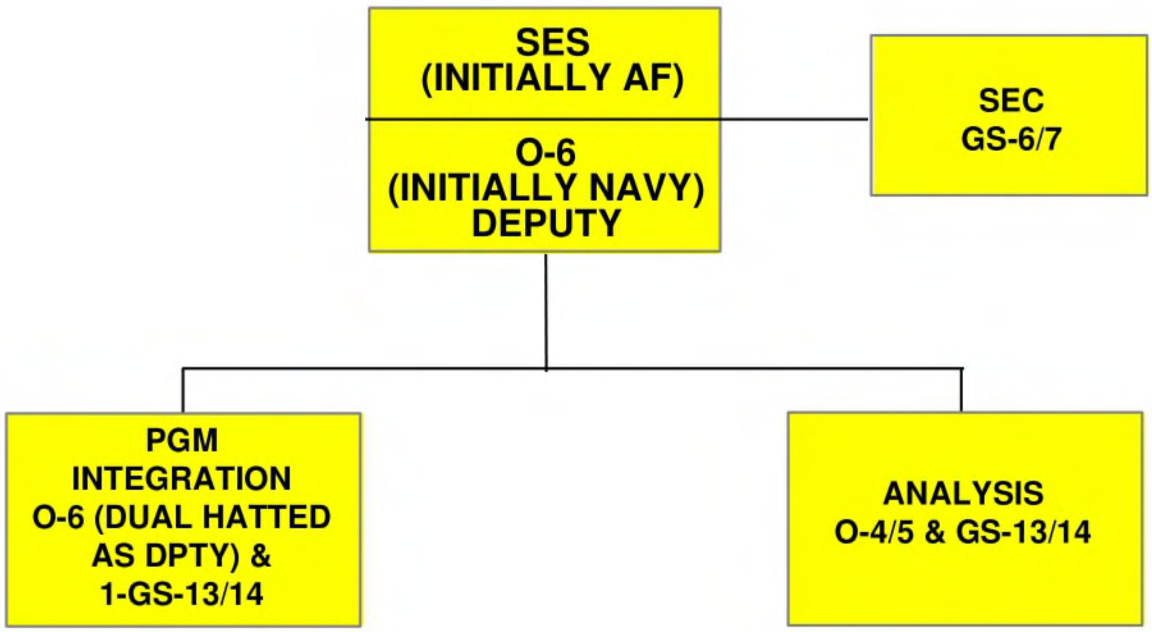
TECHNOLOGY MATURATION AND INTEGRATION



11 TOTAL
(INITIALLY)

Attachment 2

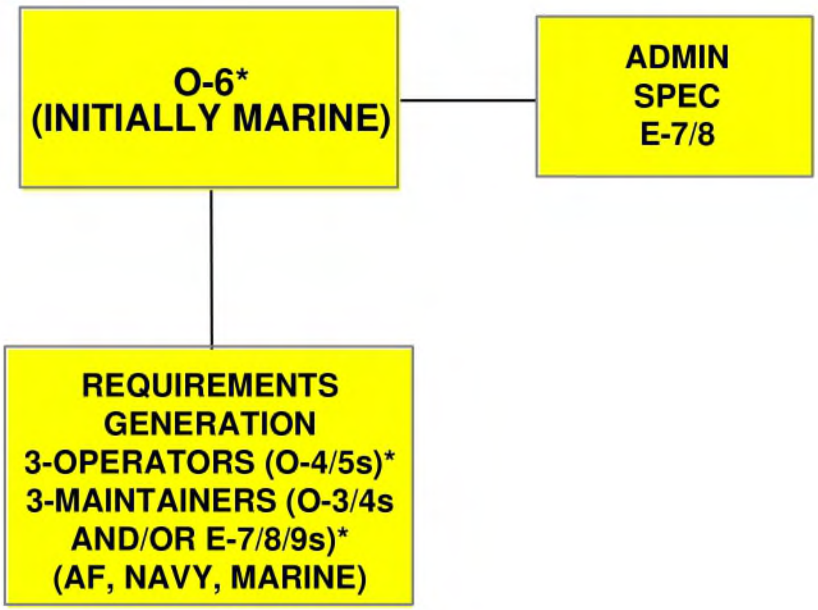
PROGRAM INTEGRATION & ANALYSIS



6 TOTAL
(INITIALLY)

Attachment 2

REQUIREMENTS GENERATION & EVOLUTION

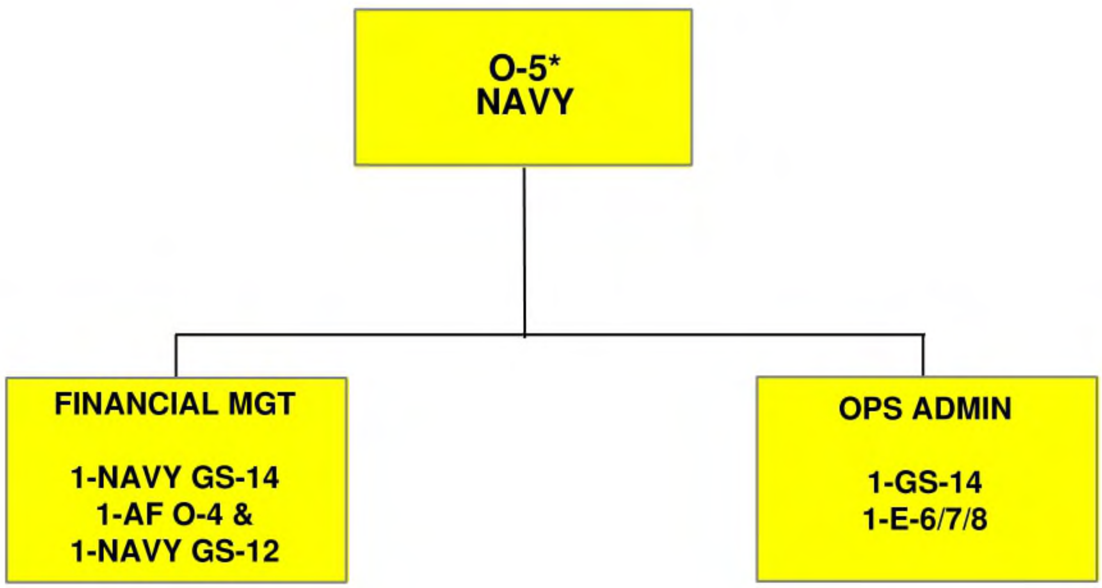


8 TOTAL

***JOINT BILLETS (7)**

Attachment 2

BUSINESS & OPERATIONS MANAGEMENT



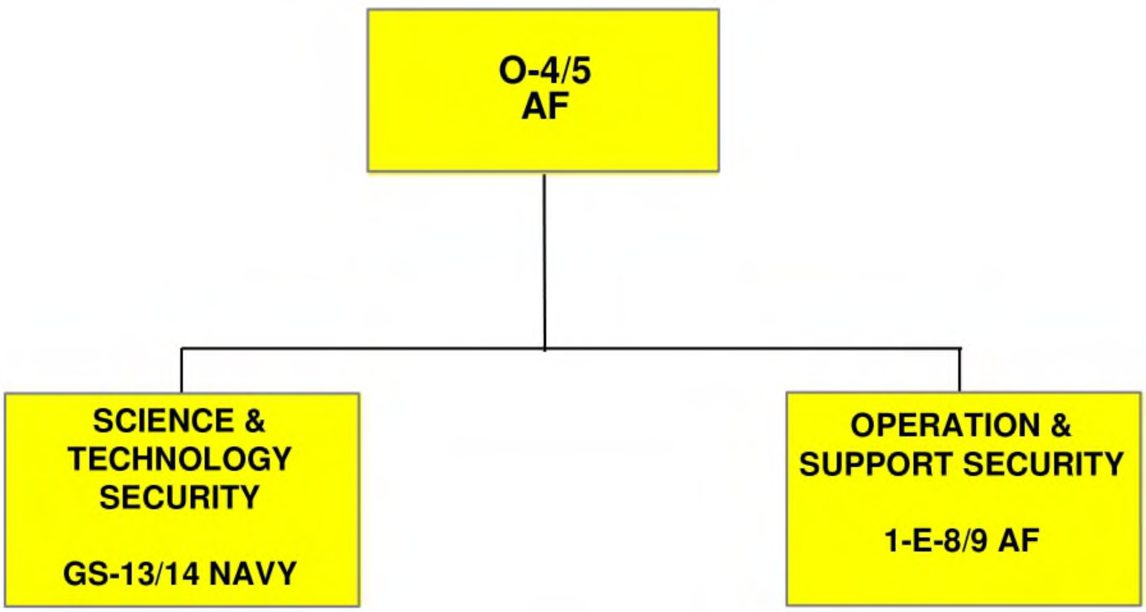
6 TOTAL
(INITIALLY)

NOTE: NEED MATRIX SUPPORT, 1-2 BUDGET ANALYSTS

***JOINT BILLETS (2)**

Attachment 2

SECURITY



3 TOTAL

NOTE: NEED CSS FOR SECURITY ADMIN & TECHNICAL SERVICES

BAA 94-1

Commerce Business Daily (*CBD*) Issue: 2/17/94
KEYWORD: 20361-2140
A – BROAD AGENCY ANNOUNCEMENT—JOINT ADVANCED STRIKE TECHNOLOGY

(JAST) STUDIES SOL JAST 94-1. Due 041594. Contact, Patrick McLaughlin, Contracting Officer, (703)-692-8030 ext. 3527, or (b)(6) [redacted] Technical [Point of Contact] POC, (b)(6) [redacted]. Broad Agency Announcement—JAST 94-1.

Introduction: The JAST Program Office, Washington, D.C. is interested in receiving proposals (technical and cost) on the research effort described below. Proposal in response to this announcement shall be submitted by 15 April 1994, 1500 hours Eastern Time, addressed to Naval Air Systems Command, 1421 Jefferson Davis Highway, Arlington, VA 22243, Room 164, to the Attention of Mr. Patrick McLaughlin, Contracting Officer. This is an unrestricted solicitation. Proposals submitted shall be in accordance with this announcement. Proposal submission after the cutoff date specified herein shall be treated in accordance with restrictions of [Federal Acquisition Regulations] FAR 52.215-10; a copy of this provision may be obtained from the contracting point of contact. There will be no other solicitation issued in regard to this requirement, however potential offerors should be alert for any announcement amendment that may be published. The JAST program office intends to provide an industry briefing on the objectives and thrust of the JAST program on 25 February 1994. For information on this briefing see CBD announcement number 40014-94 published 28 January 1994.

Requirements:

1) Technical Description: The JAST Program is seeking studies focused on innovative concepts/technologies to reduce the cost for accomplishment of joint strike warfare while maintaining current U.S. combat superiority. During the first decade of the twenty first century, many Navy, Air Force and Marine Corps tactical aircraft will reach the end of their service lives. The warfighting capability which will be lost through retirement of these tactical aircraft must be replaced. It is anticipated that this can be achieved through procurement and deployment of new strike warfare concepts. However, cost of these replacement capabilities is of foremost concern. To meet these twenty-first century needs and address this concern, JAST is seeking innovative joint strike warfare concepts, advanced technologies and improved processes to reduce the life cycle cost of conducting strike warfare and the cost of strike warfare systems. Technologies and concepts addressed in response to this solicitation, if pursued, should be able to achieve sufficient maturity to permit transition into development and achievement of initial operational capability circa 2010. Studies resulting from this solicitation will be used by joint service Integrated Product Teams (IPTs). The IPTs will apply the studies and the products of other government studies and analyses to support evolutionary definition of new strike warfare concepts and to identify high payoff Concept Demonstrations. The purpose of this Broad Agency Announcement (BAA) is to obtain studies aimed towards identifying System Concepts with high payoff potential (e.g. lower cost). Proposed studies should include innovative concepts, and/or application of advanced technologies, aimed at reducing the cost of strike warfare, while maintaining U.S. technological superiority in combat. Proposed concept studies may address the full spectrum of strike warfare systems, combinations of systems, or specific elements of strike warfare, such as advanced aircraft and weapons concepts, manned and unmanned concepts, mission planning or strike warfare command and control. Proposals which address application of advanced technologies should place primary emphasis on reducing the life cycle cost of strike warfare systems with stress on the major elements of system cost (i.e., manufacturing (unit fly away cost/decoupled from volume) and operations and support costs (to include training)) applicable to airframe, avionics and propulsion. Studies should consider differences in operating and support environment between services, approaches to maximize system commonality (e.g. modularity) and promote joint service utilization.

2) Deliverables: As a part of the proposals, bidders shall propose technical interchange meetings on an as required basis and provide interim (mid-term) and final reports. Two sets of all presentation materials and reports produced shall be supplied to the government on electronic media. Contractor format is acceptable.
3) Security Requirements: It is anticipated that work performed under this contract could be classified up to and including TOP Secret. An approved processing facility is required for proposals where classified information is to be processed. [Department of Defense Directives] (DoD DIR 5200.1-R or 5220-22-R.). Classified proposals must cite classification authority. Offerors intending to submit classified proposals should contact Major Kenneth Newsham, (703) 416-8419.

Additional Information

1) Anticipated Period of Performance: Total length of the technical effort is estimated to be six months after award.
2) Expected award date: 6 May 1994.
3) Individual contracts may be awarded in amount from approximately $0.5M to $2.0M. Multi-contract awards (up to 10 sources) are anticipated.
4) Type of contract anticipated: Cost-Plus-Fixed-Fee (CPFF).
5) Government Furnished Equipment/Information: None anticipated. Responses should clearly indicate requirements for GFE/GFI.
6) Size Status: Firms responding should indicate size status and whether Historically Black College/University (HBCU) or Minority Institution (MI).
7) Notice to Foreign Owned Firms: Such firms should be aware that restrictions may apply which could preclude their participation in this acquisition.

The JAST technical point of contact cited below should be contacted upon deciding to respond to this announcement. Proposal Preparation Instructions:

1) General Instructions: Offerors shall include a one (1) page executive summary with all proposals. The JAST Program Office may make a partial award on the basis of a proposal. To facilitate a partial award, the costs should be easily identifiable for each severable task. Offerors should apply the restrictive notice prescribed in the provision at [Federal Acquisition Regulation] FAR 52.215-12, Restriction on Disclosure and Use of Data, to trade secrets or privileged commercial and financial information contained in their proposals. Proposal questions should be directed to one of the points of contact listed below. Technical and cost proposals, submitted in separate volumes, are required, and must be valid for 180 days. Proposals must reference the above BAA number. Proposals must be submitted as an original plus one copy on electronic media. The JAST Program Office has the capability to use Microsoft Office for DOS/MAC. All responsible sources may submit a proposal which shall be considered against the criteria set forth herein. Offerors are advised that only contracting officers are legally authorized to contractually bind or otherwise commit the government.
2) Cost Proposal: The accompanying cost proposal/price breakout shall be supplied on a {Standard Form] SF 1411, together with supporting schedules, and shall contain person hour breakdown per task. Copies of the above referenced form may be obtained from the Contracting Officer cited below.
3) Technical Proposal: The technical proposal shall include discussion of the nature and scope of the research and technical approach. Concept proposals should include a description of the concept, its characteristics, system features, leveraging technologies and supporting technical analyses and quantitative data. Technology studies proposed should address application to the JAST objectives described above, cost and technical risk. The impact/payoff of these technologies should be stated in terms of system cost savings potential, system performance and mission effectiveness. Include supporting technical analyses, risk assessment and available quantitative supporting data. Key system features should be characterized in terms of their contribution to affordability, producibility and supportability (includes deployability). The name of the principal investigator, study execution plans, schedules, and resources available to support the effort should be included as attachments to the

technical proposal, and are included in the page limitations discussed below. The offeror should also include a list of past and current related contracts and [Independent Research & Development] IR&D efforts with Government points of contact. The technical proposal shall include a Statement of Work [SOW] (up to five pages) detailing the technical tasks to be accomplished under the proposed effort. The Statement of Work shall be suitable for contract incorporation. Any questions concerning Statement of Work preparation shall be referred to the technical point of contact cited in this announcement.

4) Page limitations: The Executive Summary shall be limited to one (1) page. The technical proposals shall be limited to fifteen (15) pages, including up to five (5) pages for the Statement of Work. Cost proposals shall be limited to fifteen (15) pages. Both the technical and cost portions of the proposals shall be twelve (12) pitch or larger type, double spaced, single sided on 8.5 by 11.0 inch paper. Foldouts may be used for enhanced presentation of drawings, but not as a means of increasing descriptive verbiage.
5) Preparation Cost: This announcement is a solicitation and does not commit the government to pay for any response preparation costs. The cost of preparing proposals in response to this BAA is not considered an allowable direct charge to any resulting or any other contract. It is, however, an allowable expense to the normal bid and proposal indirect cost as specified in FAR 31.205-18.
6) Format: Contractor format is acceptable for the proposed submittals.
7) Proprietary Technical Data: In accordance with [Defense Federal Acquisition Regulation Supplement] DFARS 227.403-71(a)(2), limitations of the government's ability to use or disclose such technical data or computer software will be included as a cost consideration. Accordingly, the offeror shall submit a price for which it would provide proprietary technical data to the government with Government Purpose License Rights.

Basis for award: The selection of sources for this contract award will be based on an evaluation of an Offeror's response (both technical and cost aspects) to determine the overall merit of the proposal in response to the announcement. The proposal shall be evaluated on the following criteria which are listed in decreasing order of importance:

(a) The offeror's understanding and contribution to JAST objectives;
(b) Technical merit of the proposed SOW (credibility, quality and innovativeness);
(c) Management and ability to execute (planning, scheduling, past performance, and resources available); and,
(d) Cost realism and affordability.

No other evaluation criteria will be used. The technical and cost information will be evaluated at the same time. The JAST office reserves the right to select for award any, all, part, or none of the proposals received. Selection will be based on judgment of a peer committee evaluation consisting of operators, engineers and technical personnel. Points of Contact: Contracting Officer, Mr. Patrick McLaughlin, (703) 692-8030, extension 3527; Technical Point of Contact, [redacted]—NAVAIR Synopsis No. 40021-94. (046) Commander, [NAVAL AIR SYSTEMS] Command, Code AIR-21414, Washington, DC [20631-2140]

BAA 94-1, AMENDMENT ONE

1. M!! 2. 0316!! 3. 94!! 4. 1719!! 5. 20361!! 6. A!!
7. JAST Program Office Washington, DC 20361-2140!!
8. A – BROAD AGENCY ANNOUNCEMENT—AMENDMENT 1—JOINT ADVANCED STRIKE TECHNOLOGY STUDIES!!
9. JAST 94-1 AMENDMENT 1!!
10. 041594!!
11. Contact, Patrick McLaughlin, Contracting Officer, (703) 6928030 ext. 3527, or [redacted] Technical POC, [redacted]!!

13. N/A!! 14. N/A!! 15. N/A!! 16. N/A!!

17. BROAD AGENCY ANNOUNCEMENT—JAST 94-1—AMENDMENT NUMBER 1—Evaluation criteria is clarified to read as follows: The proposal shall be evaluated using the following criteria and sub criteria. Understanding and Contributing to JAST Program objectives is substantially more important than the other criteria which are of equal importance. Sub criteria are in descending order of importance.

(a) Criteria, Offeror's Understanding and Contribution to JAST Objectives. Sub criteria: (1) Proposal contribution to significantly reduced cost for performing Joint Strike Warfare ([Research, Development, Test & Evaluation] RDT&E, Production and Operation and Support); (2) Proposal contribution to demonstration and transition of Operational Concept(s), and/or Technologies which contribute to reduced cost for Joint Strike Warfare; (3) Military Utility, (proposal contribution to al innovative solution/approach to affordable Joint Strike Warfare) effectiveness, interoperability/Joint use and preservation of future options.

(b) Criteria, Technical Merit. Sub criteria: (1) Technical Risk/Credibility (ability to successfully transition technology to a concept demonstration and development program Circa 2000); (2) Innovativeness, quality (contribution to Tech Mat and engineering validation).

(c) Criteria, Management and Ability to Execute, Ability to Execute/accomplish the work addressed in proposed study and ability to execute a concept demonstration which applies the proposed concept/technology. Considers planning, scheduling, past performance, and resources (fiscal, human, technical).

(d) Criteria, Cost Realism and Affordability. Sub criteria: (1) Affordability, cost to execute and implement the proposed effort, the study and any associated follow-up work (e.g. Concept Development, Concept Demonstration and Development). Affordability relative to potential payoff; (2) Cost realism/accuracy for execution of proposed work.

A three step evaluation process will be used. Step one will identify proposals of interest to the JAST Program. Step two will identify proposals to be recommended for funding consideration. Step three will identify proposals recommended for funding based on a coherent investment strategy which leads to affordable integrated strike warfare weapon systems. The Proprietary Technical Data and Government Purpose Rights provisions of BAA 94-1 are unchanged. The following is provided for information: It is not the Government's intent to procure data rights in connection with contracts awarded under this BAA. The pricing data is requested to support affordability assessment in the event the Government at some future date is interested in procurement of Data Rights relate to the concepts and/or technologies addressed in the studies funded by the Government. Proposals submitted without this information will not be excluded.—NAVAIR Synopsis No. 40044-94.

List of JAST & JSF Broad Agency Announcements (BAAs)

Year	**BAA**	**Purpose**
1994	94-1	JAST Concept Exploration.
	94-2	JAST Concept Definition & Design Research. Avionics, propulsion, structures & materials and supportability & training Tech Mat Modeling, simulation & analysis.
1995	95-1	Weapons integration.
	95-2	Structures & materials (canceled).
	95-3	Flight systems—JAST Integrated Subsystems Technology (J/IST).
	95-4	Avionics—Multifunction Integrated Radio Frequency Systems (MIRFS).
1996	None	(Concept Demonstration Phase RFP & Source Selection).
1997	97-1	Prognostics & Health Management (PHM).

USD(A&T) Policy Memorandum, 28 April 1995 (Excerpts)

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

APR 28 1995

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS….

SUBJECT: Reengineering the Acquisition Oversight and Review Process

In *Acquisition Reform: A Mandate for Change*, the Secretary of Defense concluded, "[DoD] must reduce the cost of the acquisition process by the elimination of activities that, although being performed by many dedicated and hard working personnel, are not necessary or cost effective in today's environment." We must move away from a pattern of hierarchical decision making to a process where decisions are made across organizational structures by integrated product teams. We must shift from an environment of regulation and enforcement to one of incentivized performance….

Integrated Product Teams (IPTs): I direct an immediate and fundamental change in the role of the OSD and Component staff organizations currently performing oversight and review of acquisition programs. In the future, these staff organizations shall participate as members of an integrated product team or teams, which are committed to program success. Rather than checking the work of the program office beginning six months prior to a milestone decision point, as is often the case today, the OSD and Component staffs shall participate early and on an on-going basis with the program office teams, resolving issues as they arise, rather than during the final decision review. Further, Program Managers (PMs) shall utilize the experience of the OSD and Component staff organizations to develop programs with the highest opportunity for success. Note that the IPTs discussed above are in addition to Program Manager/contractor IPTs established to execute programs.

For ACAT I D programs the number and level of IPTs shall be determined individually for each program by an Overarching IPT, led by the appropriate former DAB Committee Chair [because the IPT functions described above were formerly performed by DAB Committees] ….

Documentation: The documents applicable to a particular program at a specific milestone shall be determined individually for each program through the IPT process and approved by the Milestone Decision Authority (MDA). Required documents shall be determined using the concept of "tailoring in" documents (i.e., there is no set minimum number of documents beyond those statutorily required). Documents that are determined to be applicable shall be incorporated into a single document, similar to the Single Acquisition Management Plan (SAMP) used for the Space-Based Infrared System program, to the maximum extent practicable. Formats for documents shall be models, except for those formats established in statute and the Acquisition Program Baseline format….

With the exception of program plans requiring approval at the OSD level by statute, program plans are PM and IPT working tools and shall not be required as reports to the OSD or Component Headquarters staff organizations….

The Principal Deputy Under Secretary of Defense (Acquisition & Technology) shall charter a group as part of the Automated Acquisition Information effort to develop near real time flow of appropriate information to officials requiring program data, including the Program Executive Officer (PEO), CAE [Component Acquisition Executive], and Defense Acquisition Executive (DAE). The goal of this group

shall be to reengineer the entire acquisition management information and reporting system so that the PM is not creating data for reporting purposes only, but rather that the PM is reporting management data that already exists….

[Other paragraphs addressed milestone reviews and decision authorities; contracting (site assessments, inspection philosophy, and the consideration of past performance in source selections); acquisition workforce qualifications; coordination of OSD and Component audits; and implementation goals for all of the policies discussed.]

Reengineering our oversight and review process and practices is one of the most difficult issues we will face in acquisition reform. It means we will have to create a climate of reasoned, well-informed risk-management by our PMs and PEOs. Your leadership and good judgment will be critical to successful implementation of this reform. I encourage you and your leadership teams to be active participants in establishing the environment essential for implementing this change.

[signed] (b)(6) [redacted]

TAB A: OVERSIGHT AND REVIEW OF ACAT I D PROGRAMS

In the future, OSD and Component staff organizations currently performing oversight and review of ACAT I D programs shall participate as members of integrated product teams (IPTs) to build successful, balanced programs; facilitate the identification and resolution of issues early in the process; and more efficiently prepare for review of programs. These teams shall operate under the following principles:

- Open discussions with no secrets;
- Qualified, empowered team members,
- Consistent, success-oriented, proactive participation,
- Continuous, "up-the-line" communications,
- Reasoned disagreement, and
- Issues raised and resolved early.

NEW PROGRAMS

A broad, inclusive team, the Overarching IPT, shall be formed. The Overarching IPT shall be led by the appropriate former Defense Acquisition Board (DAB) Committee Chair, and shall be composed of all the Program Manager, (PM), the Program Executive Officer (PEO), and Component and OSD staff principals, or their representatives, involved in oversight and review of a particular ACAT I D program. The Overarching IPT shall structure and tailor functionally oriented IPTs to support the PM, as needed, and in the development of strategies for acquisition/contracts, cost estimates, evaluation of alternatives, logistics management, etc. The Overarching IPT shall meet immediately upon learning that a program is intended to be initiated to determine the extent of IPT support needed for the potential program, who should participate on the IPTs, the appropriate milestone for program initiation, and the documentation needed for the program initiation review. The functional IPTs shall meet as required after this determination to help the PM to plan program structure and documentation and to resolve issues. Those issues which cannot be resolved at the lowest level shall immediately be raised to a level where resolution can be achieved.

After submission of final documentation for a review, the Overarching IPT, together with the Component Acquisition Executive (CAE), shall hold a formal meeting, chaired by the Overarching IPT Leader, to determine if any issues remain that have not been resolved earlier in the process, to assess the PM's recommendations for future milestone reviews and documentation, and to determine if the program is ready to go forward for a decision. The expectation is that the IPT Leader and CAE will agree on whether to go forward; however, in the case of a disagreement, both positions will go to the USD(A&T) to decide whether to hold the DAB. The final IPT meeting will be followed by a DAB Readiness Meeting (DRM) to pre-brief the USD(A&T) prior to a DAB. In some cases, the DRM will suffice, and an Acquisition Decision Memorandum will be coordinated without holding a DAB meeting.

Through the use of IPTs, the Overarching IPT Leader will be able to provide an independent assessment to the USD(A&T) at major program reviews and/or major decision points. There should be no surprises because all team members should have been addressing the issues throughout the program phase, and should be knowledgeable of the information needed for a program decision.

EXISTING PROGRAMS

In order to move from the current process to the future process, I direct that all ACAT I D programs be "rebaselined" by the Overarching IPT Leader and the CAE. This rebaselining shall recommend the IPT

approach to be taken, the next and future review points and the appropriate level of decision authority for those reviews, and the documents needed for the next review. Within 30 days, each CAE with ACAT I D programs shall determine the order among those programs for rebaselining. The Overarching IPT Leader, working through the Overarching IPT, shall begin the rebaselining in the order provided by the CAEs. Rebaselining shall be completed within 180 days.+

DAB Committees are replaced by Overarching IPTs as described above as of the date of this memorandum. All new and rebaselined programs shall operate in accordance with the procedures for new programs discussed above. Programs for which rebaselining does not make sense shall use the IPT process to the maximum extent practicable.

August 1995 JROC Memorandum

THE JOINT STAFF
WASHINGTON, D.C. 20318-8000

JOINT REQUIREMENTS OVERSIGHT COUNCIL

JROCM 107-95
24 August 1995

MEMORANDUM FOR THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION AND TECHNOLOGY

Subject: Joint Advanced Strike Technology Program (JAST)

1. On 3 August, in preparation for a Defense Acquisition Board Program Review, the Joint Requirements Oversight Council (JROC) reviewed the JAST Program. The JROC was briefed on the Services' needs relating to JAST and the JAST Director's plan to meet those needs.

2. We endorse the JAST process and acquisition as a method of rationalizing competing requirements to meet joint warfighting needs. The Council believes delivering JAST in the 2007 to 2010 time frame is critical to alleviating future [Tactical Aircraft] TACAIR shortfalls. We strongly support the JAST Program plan to date and concur with the direction and scope of the concept demonstration phase as briefed including the program's "family of aircraft" strategy. Continuing emphasis should be placed on affordability and the Services' needs for increased capabilities in the areas of survivability, lethality, and supportability.

3. The JAST program has demonstrated a unique approach to acquisition reform that is the right direction and offers great potential towards achieving an affordable solution to meet our joint warfighting capability.

[Signed:]
Thomas S. Moorman, Jr.
General, USAF
Vice Chief of Staff

(b)(6) [redacted]
Assistant Commandant of the
Marine Corps

J. W. Prueher
Admiral, United States [U.S.] Navy
Vice Chief of Naval Operations

Ronald H. Griffin
General, U.S. Army
Vice Chief of Staff

(b)(6) [redacted]
Vice Chairman of the Joint Chiefs of Staff
JROC Chairman

Citation to Accompany the Award of the Joint Meritorious Unit Award

The JAST Program Office distinguished itself by exceptionally meritorious service from 1 January 1994 to 31 August 1995. During this period, the JAST team progressed at an incredible rate to establish a secure foundation for the successful development and production of next generation strike weapons systems for the United States Navy, Air Force, Marine Corps and their allies. The Program Office awarded over 70 contracts to begin the maturation of leveraging technologies. The resulting cost versus performance trades led to the convergence on a unique “family of aircraft”, a concept that meets the needs of all three Services with an overall potential life cycle cost savings of 33% to 55% over traditional methodologies. In addition, the JAST team produced the first tactical aircraft Joint Initial Requirements Document endorsed by the three Services. The JAST Program Office led the Department of Defense in acquisition streamlining and reform by setting new standards for joint requirements development, affordability and cycle time reduction. The JAST process proved to be highly effective and established a new benchmark for future joint programs. By their exemplary performance of duty, the members of the JAST Program Office have brought great credit to themselves and to the Department of Defense.

Given under my hand this 8th day of April 1996 ((b)(6) [redacted] Secretary of Defense).

ACAT I D Decision

[Under Secretary of Defense (Acquisition &Technology) Letterhead]

May 23 1996

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS

SUBJECT: Joint Strike Fighter (JSF) as an [Acquisition Category] ACAT I D Program

Effective immediately, the JSF is added to the Major Defense Acquisition Program list as a Joint, DoD, Acquisition Category I D program.

[signed] (b)(6) [redacted]

Copy to:
DAB Principals & Advisors

Memorandum on Milestone I Documentation Approach

[Office of the Under Secretary of Defense (Acquisition &Technology) Letterhead]

17 Jun 1996

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE
(ACQUISITION & TECHNOLOGY)

FROM DIRECTOR STRATEGIC & TACTICAL SYSTEMS

SUBJECT: Plan Of Action and Milestones for Joint Strike Fighter (JSF) program documentation

My staff and I met with members of the JSF Program Office, Acquisition Program Integration, and Defense Procurement to discuss how to proceed with documentation requirements now that JSF is an ACAT I D program. We have incorporated your desires for "tailored, phased, documentation" and propose the following documents be submitted prior to the Concept Demonstration Phase (CDP) contract award planned for November 7, 1996.

- Single Acquisition Management Plan (SAMP)
  - Acquisition Strategy—roadmap for program execution
  - Cost as an Independent Variable objectives—Balance mission needs with out-year resources
  - Concept Demonstration Phase I Exit Criteria
  - Test and Evaluation Master Plan philosophy
- Acquisition Program Baseline (APB)—Annex to SAMP

Both the SAMP and APB will be based on the first Joint Initial Requirements Document (JIRD 1) so as not to interfere with the ongoing source selection process. Drafts of these documents will be prepared by the Program Office in the August timeframe and will be reviewed by our Working Level IPT in late August. The bulk of the work has been done; it needs only to be packaged in the appropriate form. I plan to have an OIPT review of the documentation (not the program; we've done enough of that for now) in October and report those results to you in a memo immediately following. We will have the documents ready for your approval prior to the planned CDP contract award, along with a brief Acquisition Decision Memorandum which allows the program to proceed.

[handwritten:] We all agree on this approach. OK with you?
Yes [redacted] Jun 18 1996
Other _____

[signed]
[redacted]
Director, Strategic & Tactical Systems

August 1996 USD(A&T) Letter to RADM Craig Steidle

[Department of Defense Letterhead]
THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

August 22, 1996

RADM Craig Steidle
Joint Strike Fighter Program Director
1745 Jefferson Davis Highway, Suite 307
Arlington, VA 22202-3402

Dear Admiral Steidle,

I want you to know what super work you and your [Joint Strike Fighter] JSF team of professionals are doing. In particular, I believe you have made significant strides in capturing an appropriate System of Systems vision, in developing a modeling simulation base that is being done in a most comprehensive way, for moving out with your logistics approach (maintenance and sustainment) with the autonomic concept, and for making serious efforts to capture total Life Cycle Costs (LCC) and then use them in future program tradeoffs.

I believe that LCC may well be one of the toughest areas to get your arms around, but I ask that you pay particular attention to this area because of the huge payoffs.

I was quite impressed with the team you have pulled together on JSF. While they represent a combination of three different services, as well as allies and members of the industrial community, they are certainly performing as a cohesive unit.

Please pass along my thanks to all your super folks for their hard work in making this visit a great success. I believe you are off to a strong start and are on the right course. I look forward to working with you and hearing similar updates.

Best regards,

[signed]
(b)(6)

Milestone I Acquisition Decision Memorandum

[USD(A&T) Letterhead]

Nov 15 1996

MEMORANDUM FOR SECRETARY OF THE AIR FORCE
(ATTENTION: ACQUISITION EXECUTIVE)
SECRETARY OF THE NAVY
(ATTENTION: ACQUISITION EXECUTIVE)
DIRECTOR, PROGRAM ANALYSIS AND EVALUATION
DIRECTOR, STRATEGIC AND TACTICAL SYSTEMS

SUBJECT: Joint Strike Fighter (JSF) Milestone I Acquisition Decision Memorandum (ADM)

Per my earlier direction, on October 22, 1996, an Overarching Integrated Product Team (OIPT) reviewed program documentation for the JSF Program prior to its entering the Program Definition and Risk Reduction (PDRR) phase.

I approve entry into PDRR. I also approve the attached: updated acquisition strategy, PDRR exit criteria, Cost as an Independent Variable (CAIV) objectives, and the Acquisition Program Baseline.

Please conduct an Analysis of Alternatives (AOA) in preparation for Milestone II. The Director, Program Analysis and Evaluation, working with the Services and the Program Office, will within 120 days of this ADM propose final AOA guidance for my approval.

[signed] (b)(6) [redacted]

Attachment

Citation to Accompany Award of the David Packard Excellence in Acquisition Award

Presented to: Department of Defense, Joint Strike Fighter Program Office (JSF) Program Management Integrated Product Team.

In recognition of Acquisition Excellence and Superior Performance, as the Department of Defense's flagship innovative family of aircraft program for developing and deploying affordable next-generation strike aircraft weapon systems for the Navy, Air Force, Marines and Allies. The Joint Strike Fighter's Program Office employed acquisition reform initiatives—reducing development, production, and ownership costs.

(March 17, 1997—(b)(6) [redacted], Under Secretary of Defense for Acquisition and Technology)

Citation to Accompany Award of the Air Force Acquisition Lightning Bolt Award

Presented to: Joint Strike Fighter (JSF) Source Selection Team.

For outstanding contributions and diligence in developing and implementing innovative processes and practices in support of the SAF/AQ Lightning Bolt Initiatives. Your efforts will have an enduring effect as the Air Force moves forward to rebuild the acquisition system.

(March 1997 – Ronald R. Fogleman, General, USAF, Chief of Staff of the Air Force and Sheila E. Widnall, Secretary of the Air Force)

1988 ASTOVL Desired Operational Capabilities Document

[Department of Defense Letterhead]
DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, D.C. 20350

25 Feb 1988

FROM: Deputy Chief of Naval Operations (Air Warfare)

SUBJECT: Naval Desired Operating Characteristics for an ASTOVL Fighter/Attack Aircraft

1. Recently members of your staff briefed VAdm McCarthy, LtGen Smith, and me concerning your ongoing research regarding development of an Advanced Short Takeoff, Vertical Landing (ASTOVL) fighter/attack aircraft. The ASTOVL concepts and technologies being investigated in the ASTOVL project show great promise for providing the Naval Services with a follow-on light attack and fighter-attack aircraft to replace the F/A-18 and Av-8B when they reach the end of their service lives in the 2002-2010 timeframe.
2. Your briefing requested that the Services describe any requirements we might have for such a vehicle to help focus your technology maturation efforts. To this end LtGen Smith's and my staff have been working with your engineers and NASA to develop a desired operation characteristics document. This document is attached. It is realized that not all of these perceived requirements are totally compatible (e.g., performance and signature goals), but we hope that with this early start you and industry will be able to mature and integrate the technologies relevant to filling our needs.

[signed]
R. F. Dunn
VAdm USN
Deputy Chief of
Naval Operations
(Air Warfare)

[signed]
K. A. Smith
LtGen USMC
Deputy Chief of Staff
for Aviation

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